Electricity Market Reforms and Renewable Energy:
The Case of Wind and Solar in Brazil

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ABSTRACT

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This dissertation investigates the relationship between electricity market reforms and the development of renewable energy through interviews with policymakers, energy experts, and industry representatives in Brazil. Within the context of market-oriented power reforms initiated in the 1990s, policymakers have attempted to diversify the energy supply and reduce the country's reliance on hydroelectric power. However, Brazil's pre-existing hydropower infrastructure has hindered the diffusion of alternative options. By looking at energy auctions and net-metering regulations for wind and solar energy, this research explores the role of independent regulators in facilitating the development of non-hydro renewable sources of energy. While academic and policy debates center on designing public support schemes for renewable energy, this research argues that adaptive regulation can provide opportunities for new technologies that policy instruments alone are unable to achieve. In particular, the governance characteristics of regulatory agencies are critical to the effective articulation of renewable energy policies. Three subnational case studies further demonstrate how states and regions contribute to developing and deploying wind and solar energy technologies.

Table of Contents

List of Abbreviations

ANEEL	Brazilian Energy Regulatory Agency
BNDES	The Brazilian Development Bank
CCEE	Electric Energy Trading Chamber
CEPE	State Committee for Energy Policy
CERNE	Strategies Center for Natural Resources and Energy
CNPE	National Energy Policy Council
CONFAZ	Brazilian Council for Financial Policy
DNAEE	National Department of Water and Electric Energy
EIA	Environmental Impact Assessment
EIA	U.S. Energy Information Administration
EMBRAPA	The Brazilian Agricultural Research Corporation
EPE	The Brazilian Energy Planning Enterprise
ETA	Energy Tax Act
FERC	U.S Federal Energy Regulatory Commission
ICMS	Merchandise and Services Circulation Tax
IEA	International Energy Agency
IRA	Independent Regulatory Agency
IRENA	International Renewable Energy Agency
MME	Ministry of Mines and Energy
MLP	Multilevel Perspective
NFFO	Non-Fossil Fuel Obligation
OECD	Organization for Economic Cooperation and Development
OFGEM	U.K. Office of Gas and Electricity Markets
OPEC	Organization of the Petroleum Exporting Countries
PURPA	Public Utility Regulatory Policies Act
PROGD	The Program for the Development of Distributed Generation of Electric Energy
PV	Photovoltaic
RO	Renewables Obligation
RPS	Renewable Portfolio Standards
TIS	Technological Change and Innovation Systems
SDEC	Economic Development Secretariat of Pernambuco State
SEDEC	Economic Development Secretariat of Rio Grande do Norte State
SEM	Secretary of Energy and Mines of São Paulo State
SIN	Interconnected Transmission System
TCU	Federal Court of Accounts

UFRJ	Rio de Janeiro Federal University
UNCED	United Nations Conference of Environment and Development
UNICAMP	State University of Campinas
ONS	National Systems Operator
USP	University of São Paulo

List of Tables and Figures

Tables

Figures

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I dedicate this dissertation to them.

Chapter 1

Introduction

"Carbon, like the state, is not withering away."

- Unruh and Carrillo-Hermosilla (2006, p.1189)

In the 1980s, a global pro-market shift sought to dismantle the public ownership and provision of basic services. Advocates of free market principles called for the privatization and deregulation of critical infrastructure industries. For electricity sectors, the general understanding was that providing electricity should be an apolitical, technical enterprise. State-run energy utilities were to give way to an efficient and low-cost private sector model of service delivery. Independent regulatory agencies were fundamental to these new economic governance arrangements, which were intended to administer a hands-off, rule-based approach to the correction of market failures (Baldwin, Cave, & Lodge, 2012), as opposed to regulating for reasons of distributional justice, rights protection, and environmental degradation (Prosser, 2010). These developments gradually crystallized into what has been referred to as the "standard model" for power sector reform (Gratwick & Eberhard, 2008; Joskow, 2008; Victor & Heller, 2007). Driven by ideology, financial crises, and early success stories, most countries have drawn on the basic tenets of the standard model to reform and, on occasion, remake their electricity sectors.

As governments embarked on power reform agendas to increase competition and private sector participation, other social and environmental goals were coming to the forefront. The OPEC oil crisis in 1973 and the Chernobyl nuclear disaster in 1986 had alerted countries not only to the degree to which they depended on fossil fuels, but also to the need for safe and renewable sources of energy. The growing awareness that the majority of global greenhouse gas emissions (GHGs) were a by-product of the dominant energy production technologies further solidified the notion that decarbonizing electricity sectors was an urgent matter, and a few countries began to make concerted efforts to utilize small hydropower, biomass, and wind power. Yet, academic and policy debates over electricity reforms largely focused on creating independent regulatory agencies and competitive markets (Bacon & Besant-Jones, 2001). Public support for renewable energy was seen as distorting electricity markets and providing an "unfair advantage" for environmental technologies. As a result, there has been less attention given to the social and environmental implications of power reforms (Dubash, 2003; Dubash & Morgan, 2013).

Furthermore, the literature on evaluating policy instruments for renewable energy often assumes that carrying out a given policy framework is a purely administrative or apolitical process (Menanteau, Finon, & Lamy, 2003; Wiser, Barbose, & Holt, 2011). When policies fail to effectively increase a country's share of renewable energy, policy analysts prescribe clearer rules or more carefully designed incentives to improve implementation outcomes. A policy's design features, however, say little about its implementation – in this case, the processes and program activities that occur between high-level consensus on instrument design and the successful construction of a renewable power facility. This observation is particularly relevant to restructured electricity markets, where renewable energy programs often lie in the hands of regulators who monitor sector investments. Regulators apply and interpret policies in individual cases, constituting policy on the ground while dealing with unforeseen issues that policymakers did not, or could not, anticipate.

This dissertation examines the role of sector reforms and regulatory institutions in the integration of wind and solar energy into electricity production in Brazil from 1992-2017. To this end, I conducted 43 qualitative, semi-structured interviews with regulators, policymakers, and energy professionals to investigate how the Brazilian Energy Regulatory Agency (Aneel) has supported the diffusion of renewable energy. I also conducted expert interviews in the states of São Paulo, Pernambuco, and Rio Grande do Norte to analyze the institutional and political mechanisms that shape the market formation of renewable energy at the regional level.

An ongoing trend in regulatory reforms is to re-organize electricity sectors around economic arguments. To this extent, regulatory agencies are expected to focus wholly on economic and supportive administrative matters and treat the regulated industry as a problem of technical management. Countering this reform model driven by economic considerations, and top-down understandings of policy implementation, I found that the line between policy and regulation is not so clear. Political and administrative settings shaped regulators' values and interests, and thereby influenced how they translated renewable energy policies into practice. Moreover, rather than lagging behind or opposing technological change, regulators have taken on an enabling role for new renewable technologies. In so doing, the standard model for electricity reform would predict a highly inefficient energy sector shunned by private investors. In fact, Aneel’s willingness to lead in regulatory policy-making has improved the sector’s legitimacy and credibility. A closer look at regulatory practice is thus critical for understanding how electricity reforms affect renewable energy outcomes.

The Brazilian electricity sector reveals how electricity reforms and institutional settings can create opportunities for renewable energy development. Brazil is distinguished by its centralized state involvement and an electricity mix dominated by hydropower. Capturing the energy of falling water, hydroelectric plants generate up to 85% of the country's electricity on a given day, whereas the global average wavers around 16% (IEA, 2014). It is also the 9th largest producer of electricity in the world (CIA, 2015). In the midst of an economic crisis aggravated by the poor financial performance of state-owned companies, Brazil entered the worldwide trend of market-oriented reforms in the 1990s. The power sector was rebuilt on the idea that new regulatory agencies would govern the private sector companies henceforth responsible for energy infrastructure. At the same time, the conventional view shared by politicians, utilities managers, and the general public was that the country should continue to exploit its "natural abundance" in hydrological resources, implying that non-hydro energy sources were to have a limited role. Therefore, while carbon emissions from electricity generation in Brazil are low compared to other countries, the hydroelectric system has created a situation of "lock-in" (Unruh, 2000). In other words, hydropower's institutionalized features and characteristics have made it difficult to introduce alternative energy technologies that could improve the electricity sector by bolstering supply security and offering new solutions to providing power to consumers.

Within this technological and institutional landscape erected by hydropower, the cases of wind and solar illustrate how regulators have gained authority to facilitate the deployment of emerging renewable technologies. To analyze the case of wind energy, I focus on how the energy regulator, Aneel, has administered Brazil's main policy support instrument, energy auctions, to increase its renewable energy capacity. Following electricity reforms, in 2004 the Brazilian government enacted an auction scheme to set target levels of investment in renewable energy. In practice, auctions do not guarantee that renewable energy projects will be built. Awarded projects can experience delays, or become abandoned after an auction has taken place. By mediating "troublesome" wind projects on a case-by-case basis, the success of Aneel's implementation strategy depended on how it held project developers liable to their obligations as market participants. Aneel also collaborated with industry stakeholders to find adaptive solutions to regulatory problems that emerged during implementation. Auction results may thus initially look favorable and lower the price for electricity, but Aneel's reputation for enforcement and being a collaborative problem-solver in the electricity sector contributed to the effective implementation of wind energy.

In the case of solar energy, Aneel has taken the lead to promote small-scale photovoltaic (PV) systems. My examination of solar differs from the case of wind energy in that it presents a chronological analysis of the development of distributed generation regulations. When the electricity industry was re-structured in the 1990s, the new rules of operation were rebuilt around the characteristics of large hydroelectric generators. Specific rules and regulations did not exist for small-scale generation systems. Aneel has used this policy gap as an opportunity to advance the widespread deployment of distributed generation technologies. Since 2008, Aneel has built out the governing framework for net-metering to compensate small-scale system owners for the electricity they supply to the grid, using each regulatory review as an opportunity for learning and iteration. At the same time, incumbent utilities have often proven hostile to new policies, speaking out against Aneel's authority to provide regulatory support for distributed generation. In response, Aneel has had to defend its authority while using public consultation procedures to consolidate a broad coalition that supports distributed generation technologies. Regulators have strategically used the dynamic nature of the implementation process to adapt the electricity system to the characteristics of small-scale solar energy.

This study further examines the transition of the energy system by focusing on the regional scale. While much of the academic discussion about energy systems has centered on the policy positions of national governments to replace fossil fuels with low-carbon alternatives (Jacobsson & Bergek, 2004; Kern & Smith, 2008; Verbong & Geels, 2008), scholars have pointed to how conditions in particular locations support technological alternatives and energy transitions (Bulkeley et al., 2010; Smith, 2007; Truffer, Murphy, & Raven, 2015). The three Brazilian states of Pernambuco, Rio Grande do Norte, and São Paulo were chosen as comparative case studies to analyze the regional factors that have supported or impeded the implementation of wind, solar, and distributed solar energy generation. The main questions addressed in this study are: What regional initiatives and policy processes have emerged to stimulate the deployment of wind and solar in Brazil? Furthermore, to what extent can regional transition processes and policies complement or strengthen national energy planning and prerogatives?

I found that state governments have an underappreciated role in devising initiatives to support wind and solar energy technologies. In addition to natural resource endowments, each region has its own geography, industrial base, and political context that lend more or less credibility to arguments about what energy sources should be developed within its borders. Renewable energy programs in Pernambuco and Rio Grande do Norte have convinced federal authorities that solar and wind technologies could compete in energy auctions, breaking political inertia at the federal level. Prior investments in energy infrastructure and hydroelectric expansion also structure energy governance at the regional level. For example, moving large amounts of hydroelectricity to power cities in the South was the overriding principle in planning long-distance transmission lines. Under this system, semiarid states in the Northeast were not conceived of as energy producers because of their lack of hydrological resources. The consequent absence of transmission lines to connect these regions of high wind potential is one of the main barriers to developing wind energy in the country. Similarly, São Paulo's choice to emphasize natural gas and biogas, instead of wind and solar, can be explained by the state's plentiful offshore oil and natural gas reserves and status as the main sugarcane ethanol producer state in the country.

The main contributions of this dissertation speak to the debate over how institutional arrangements influence the implementation of renewable energy markets. The standard model for power reform has approached "politics" and "weak institutions" as barriers to be cleared in order to sideline the state and provide space for markets to operate properly (Ayres & Braithwaite, 1992; Victor & Heller, 2007). Similarly, the "politics" of regulation are often overlooked for renewable energy policies, where policy analysts focus almost exclusively on design elements to improve project outcomes. By drawing attention to the institutional and socio-technical dimensions that govern renewable energy policies, I argue that the implementation of renewable energy programs is inextricably tied to the institutional values of regulators. Given that energy regulators have to enforce rules and decisions that are regularly challenged by private actors and other public authorities, they seek to ensure support for wind and solar energy in ways that reinforce their legitimacy and authority in the electricity sector. Aneel's credibility in negotiating the tensions between regulatory stability and adaptive policymaking is critical for the long-term governance of wind and solar energy.

This dissertation is organized as follows. Chapter Two presents the theoretical literature on which this dissertation is based. It first reviews the "standard model" for electricity reform and the contested purpose of utilities regulations, aiming to show the progression of regulation from its conception as economic management to the gradual recognition of regulation's diverse political and social objectives. It also surveys the use of public policies to stimulate renewable energy and analytical approaches to studying socio-technical transitions in energy systems. Chapter Three then summarizes the research design and methodology. Chapter Four traces the processes and power sector reforms that have influenced the present regulatory structure in the Brazilian electricity sector. Public support schemes for renewable energy are shown to be influenced by the rules and socio-technical characteristics of an electricity system defined by hydroelectric power. Seen in this light, the work of regulators gains importance in aligning the institutional setting to the needs of non-hydro technologies. Chapter Five turns to the regulatory approaches for wind and small-scale solar energy, and how and why energy regulators have prompted distinctive organizational processes for each type of energy technology. Chapter Six examines the three state case studies of São Paulo, Pernambuco, and Rio Grande do Norte, describing under what conditions states exercise autonomy to set policy agendas for solar and wind technologies.

Chapter Seven presents this dissertation's conclusions and policy implications. Together, these findings demonstrate that independent regulation, a central element of electricity restructuring, is also a potentially effective site for social and environmental policy. In Brazil, regulators have frequently taken the lead to ensure the implementation of wind and solar technologies which have been characterized, to varying degrees, as less compatible with the underlying policy regime. It is thus more useful to jettison the false dichotomy of policymaking versus economic regulation. An inherent part of what regulators do is fill in the details of broad government policy. The fact that they oftentimes accomplish this in ways that adhere to their organizational values and preferences does not necessarily conflict with their regulatory mandate. Rather, the regulatory setting is an overlooked aspect for understanding effective renewable energy policies. Within this changing policy environment, state governments demonstrate a wide range of policies and responses. States that exhibit a strong commitment have contributed to the learning and technological development of renewable alternatives that, until recently, have not been given priority at the federal level.

Chapter 2

Literature Review

Since the 1980s, the utilities industry has transitioned from a model of government ownership to market-based paradigms. Independent regulatory agencies emerged as a key component of a globally applied model for reforming and restructuring electricity sectors. Theoretically insulated from political pressures, independent regulation was intended to ensure economic efficiency and provide stability for market participants. It has generally not been considered an effective nor appropriate means for achieving policy objectives, such as the development of renewable energy. In this regard, opponents of government intervention have stressed that regulatory activities should be restricted to maintaining industry efficiency, while advocates of renewable energy have often portrayed regulations as barriers to innovation. As a result, little attention has been paid to the possible enabling role of regulators and regulatory frameworks in energy transitions.

This chapter begins by reviewing conventional and alternative perspectives to restructuring and regulating public utilities. It then surveys the use of public support schemes to promote renewable energy sources, and analytical frameworks for studying how energy-based socio-technical systems develop, diffuse, and block new renewable energy technologies. A main feature of these approaches is that institutional and regulatory change is crucial to the successful diffusion of renewable energy. It then discusses previous contributions to local and regional approaches to energy transitions research. The chapter concludes by explaining how this dissertation will contribute to the literature on renewable energy transitions and regulatory policy-making.

2.1. The Standard Model for Electricity Reforms

Largely due to ideological reasons, the 1980s marked a fundamental rethinking of the government provision of basic services. The traditional justification that utilities should be publically owned and operated was called into question. In particular, the idea of “state failure” came to explain a range of challenges facing electricity, telecommunications, water, and roads. Opponents of Keynesian ideas held the state responsible for a legacy of underinvestment in infrastructure, poor service quality, and insufficient revenue (Furlong, 2012, p. 2722). In a few short years, there was a rush to anoint a new conventional wisdom—that privatization and competition in utilities sectors was not only possible, but inevitable (Dubash, 2003, p. 144). The shift from public monopolies to governance arrangements that encouraged private sector participation came to be seen as the more appropriate and efficient means to manage infrastructures (Graham & Marvin, 2001; Sanyal, 1994, p.7).

In developing countries, the state-led provision of basic services was also under attack by both the right and the left. In the 1950s and 1960s, economic policy had assigned the state a substantial role in economic development and industrialization (Bresser-Pereira, 2009; Johnson, 1982; Wade, 1990; 2003). The dominant development paradigm at the time was defined by government intervention oriented towards the long-term growth needs of underdeveloped economies. By the 1970s, however, the project of development had yet to deliver on its robust promises and many countries were still experiencing disappointing economic performance. Consequently, development economics and its focal actor, the state, were charged with the intellectual responsibility for what went wrong (Hirschman, 1981, p.19-23; Sanyal, 1994). This growing distrust in the ability of the state to provide conditions for economic development provided a critical opening for neoclassical economists who were finally able to gain traction and express misgivings that state intervention was inefficient, even perverse (Lal, 1983). Moreover, in unexpected agreement with the neoclassical critique, neo-Marxists echoed political capture theories, claiming that the developmental state had been co-opted and had stymied real systems change (Hirschman, 1981, p.14; Sanyal, 1994).

As a result of this far-reaching intellectual shift, proponents of a new model called for the withdrawal of the state and more involvement of the private sector. The privatization of government services and infrastructure began to be touted as a solution to the problems of big government, fiscal deficits, and the need to rebuild infrastructure and expand the provision of basic services. Simultaneously, the philosophies embodied in the "new public management" emphasized forced budget reductions and the contracting out of additional responsibilities to the private sector or third-party organizations when government involvement could be judged as inefficient or redundant (Smith & Lipsky, 1993; Osborne & Gaebler, 1992; Wilks, 1996, p. 541). These reforms sought to increase administrative efficiencies and provide greater autonomy and higher levels of consumption based on individual utility. The growing currency of the term "service delivery" reflected individual claims to consumption, not collective ones, and the treatment of basic services as commodities (Herman & Ausubel, 1988; Whitefield, 2001).

In short, the pro-market shift deeply transformed both the goals and the means of public policy. According to Majone (1997), in the post-war era of economic reconstruction, mainstream public policy in the West centered on discretionary macroeconomic management and industrial planning. In contrast, it now centers on making markets and making them work (Majone, 1997, p. 147). The Washington Consensus further consolidated and transmitted these characteristically "neoliberal" policy recommendations to debt-ridden countries in the global South. International lending institutions, such as the World Bank, the International Monetary Fund, and the

International Development Bank began to approach privatization as a necessary, technical matter (Goldman, 2006, p. 60; Kapur & Lewis, 1997).The selling off of state-owned utilities assets to private firms was often required in their project lending for large capital investments.

For electricity sectors, a “standard model” for reform gradually replaced state ownership and operation. First informed by developments in primarily industrialized countries, such as the United States, the United Kingdom, and Norway, this model has been applied throughout the developed and developing world (Gilbert & Kahn, 1996; Gratwick & Eberhard, 2008, p.567). Previously, government ownership of electric utilities monopolies was often justified on the grounds that the state was the best custodian of the public interest (Gratwick & Eberhard, 2008). These public utility companies were typically vertically integrated and offered a full range of power services, including transmission, distribution and generation, all of which they directly controlled to ensure coordination among these different segments. These firms in turn were granted exclusive franchises to supply electricity to residential, commercial and industrial retail consumers within a defined geographic area (Joskow, 2008). The main difference across countries was whether the utility monopolies were publicly or privately controlled, with the United States, Germany and Japan exhibiting significant private ownership, albeit with heavy government regulation of the industry. Most countries, however, opted for public ownership (Gratwick & Eberhard, 2008, p. 3949).

Under the standard model, private sector participation was highlighted as the means to improve sector performance and make electricity production more efficient and less costly. Ideology played a significant role, and reforms were meant to address utilities’ ostensibly poor financial management and restrict the state’s ability to use public utilities to pursue costly political agendas. In practice, improving sector competition translated into separating generation and retail supply from segments that continued to be regulated, such as distribution and transmission. This "unbundling" of the electricity-supply function from distribution was based on the theory that only the wires (the fixed network system) constituted a natural monopoly, whereas the generation of power did not (Lazar, 2016, p. 9). These reform efforts were also meant to attract investments in infrastructure as the public sector was seen as no longer able to provide the requisite funds for system expansion (Jamasb, 2002).

The establishment of credible regulatory agencies was seen as a fundamental step to restructuring electricity sectors (Jacinct & Morgan, 2012; Jordana & Levi-Faur, 2004; Vogel, 1996; Wilks, 1996). Reformers argued that the growing reliance on the private sector necessitated a governmental capacity to manage public-private relationships (Kettle, 1980, p.6), while maintaining a critical distance from the traditional bureaucracy. In this light, independent regulatory agencies were placed at the center of redesigning infrastructure sectors. In developing countries, they were often part of loan conditions set by multilateral development banks that prescribed deregulation and restructuring (Dubash & Morgan, 2013).

Studies of electricity reform have focused on the optimal design for these new regulatory agencies. Above all, the literature has underscored that agency independence and autonomy should insulate utilities from other branches of government. An enduring concern in regulatory policy-making is that of political manipulation, whereby arbitrary government actions can undermine regulatory credibility and consequently discourage private investment (Dubash, 2005). Relatedly, a common practice has been for governments to use state-owned electricity utilities to play a number of political functions such as industrial growth and macroeconomic stabilization (Victor & Heller, 2007). Governments have often required electric utilities to supply low-priced electricity or have manipulated electricity prices as part of anti-inflationary programs.

For example, during bouts of hyperinflation in Argentina and Brazil in the 1990s, the price for electricity was reduced, only to be drastically increased later (Spiller & Martorell, 1996, p.91).

The debate over regulatory design also centers on financial independence and sector-specific training. In order to be able to dispense the right incentives, reward or punish performance, and establish reliable rules, a common argument is that regulatory agencies should have their own source of revenue removed from the general budget process. If the regulatory agency were to depend on general appropriations from the treasury, it could be subjected to "political retaliation" for its decisions. Furthermore, regulatory policy should be administered by a professional class of experts equipped with a more competent understanding of technical issues. Prior to the establishment of independent regulatory agencies, untrained politicians or civil servants had generally not been recruited based on merit or specialized technical knowledge of the sectors that they administered (Guasch & Spiller, 1999, p. 77; Jordana, Levi-Faur, & Marín, 2011). They thus lacked the expertise to make decisions about technical matters. A lack of academic training was also believed to compromise a regulator's dedication to unbiased decision-making, leading to judgements based on political considerations. Therefore, it has been recommended that regulatory agencies recruit and retain qualified and experienced employees.

2.2. The Politics of Utilities Regulation

While regulatory agencies have been central to market-oriented reforms, the normative debate continues to be polarized by those who favor and those who oppose regulations based on ideological grounds. Critics often treat regulation as imposing a burden. While regulation may be needed, they portray regulatory intervention as a second-best choice to markets and private orderings (Shleifer, 2005, p. 440). Competition and "freer" markets are advanced as the preferred solution to protect consumer welfare and prevent industry from abusing its market position

(Costello, 2009; Prosser, 2010). On the other hand, proponents of regulation emphasize an agency's role in protecting public interests. Such actors involved in the regulatory process are said to seek the “best” policy, in some civic sense, and are not motivated principally by individual self-interest or the prospect of personal gain. As part of their mandate, regulators exercise authority to protect the public from the abuse of private economic power, particularly monopoly behavior (Levine & Forrence, 1990, p. 168; Vogel, 1996, p. 10).

Stemming from this underlying ideological debate, the purpose of utilities regulation varies with one’s perspective. Economic theories have greatly influenced approaches for designing and evaluating systems of regulation. Economists see regulation as a means to exploit economies of scale from natural monopolies while reducing economic loss in markets with imperfections, such as high entry barriers and insufficient information (Hempling, 2013). The challenge for regulators is consequently to strike a balance in order to protect consumers and enhance efficiency without choking off private initiative. When a market is characterized as a natural monopoly, which has traditionally been the case for water and electricity, or when a sector that was once dominated by a handful of state-owned firms is privatized, regulation is often seen as necessary to avoid rent-seeking behavior. Another task for regulators is to devise a “rate-of-return” regulation or some form of cost-based pricing which sufficiently remunerates the investments of private investors while penalizing inefficiency. For example, in setting prices for electricity, regulators are often directed to set rates that are “just and reasonable” to provide the utility an opportunity to earn fair returns (Lazar, 2016).

A related perspective based on economic institutionalism contends that regulations are the best method to enforce contracts that safeguard the interests of both consumers and producers. For utilities and infrastructure sectors characterized by high fixed costs and government concessions, long-run contracts play an important role. Influenced by transaction cost economics (Coase, 1960; Williamson, 1975; 1998), regulations are viewed as fundamental to the establishment and enforcement of property rights that provide the security needed for long-term investments and adequately handling market opportunism and uncertainty. Through regulatory agencies, government can formalize and institutionalize its commitments to protecting consumers and investors by maintaining contracts. Regulators and commissioners have the power to monitor, enforce, and review contracts and, in particular, to modify these contracts following a review (Stern, 2012; Williamson, 1998). In upholding the goals of economic regulation, contract monitoring and enforcement assures that consumers receive goods and services from private providers at a reasonable price, while protecting private investors from sudden changes to the "rules of the game."

In recent years, this paradigm of the public utilities regulator that restricts its activities to economic management has been challenged. One view from political science is that the recalibration of state–market relations in the 1990s transformed both the goals and the means of public policy. In this sense, regulatory institutions have increasingly been responsible for social and political goals that the welfare state once handled directly (Majone, 2007; Vogel, 1996), in addition to managing markets. In a similar manner, there has been concern that few studies on regulations and infrastructure provision accurately reflect the experiences of developing countries. When it comes to social provisions, there has been a historical inadequacy to achieve universal access to electricity or to mitigate the environmental impacts caused by certain energy choices. In cases where urgent policy concerns have not been adequately solved by direct state intervention, policy-oriented regulations could be more appropriate remedies. Scholars of developing countries have notably emphasized that the neat distinction between efficiency and social interests, a frame often used by economic theories to evaluate systems of regulation, may not take into full consideration the unique social and political conditions facing infrastructure sectors in developing countries (Dubash, 2005; Dubash & Morgan, 2013; Gratwick & Eberhard, 2008).

In addition to changing models of political economy, scholars and practitioners have broadened the concept of utilities regulation to consider a wide range of rationales that include social functions and responsibilities (Prosser, 2010, p.2). The view that economic, social, and distributive goals are typically inseparable has gained traction with critics of the standard model. A major point of contention is that efficiency-enhancing regulations do not necessarily guarantee that markets can adequately supply public goods. For example, a major concern is that power sector reforms will be harmful to the poor and low-income households (Dubash 2003; Haber, 2010; von Schnitzler, 2016). Even in a functioning market and regulatory regime in which suppliers meet all regulatory demands, citizens may still face high energy bills or disconnection due to an inability to pay. Instead, regulation may be a first choice to administer an arena of social provision for which markets are considered inappropriate (Prosser, 2010, p.3).

Scholars further argue that utilities regulation is necessarily a political endeavor. Since regulatory agencies operate at the intersection of both public and private sector influences, it may not be useful to maintain conceptual boundaries between “policymaking” and “regulating.” In practice, both policymakers and regulators make policy (Brown, 2003). The distinction is that policymakers define the fundamentals and parameters within which policymaking is delegated to regulators. Within the scope of authority granted to them by the government, regulators exercise discretionary power in pursuit of regulatory goals. An inescapable fact of regulatory life is that regulators make choices as to what aspects of their regulatory remit they will try to achieve, and those that it will not (Black, 2006, p.157). In cases where they have limited policy guidance from government ministries, regulators have a capacity to pursue a goal in ways that best promotes that goal, or in areas where rules are absent, ambiguous, or conflicting (Forsyth, 1999). In effect, regulators carry out their mandates and adjudicate priorities in ways that deviate from their original apolitical design, and this is a natural part of the policymaking process.

Therefore, as the administrative patrons of broader polices, regulators have the discretion to reinterpret what a policy means. They can choose to act or refrain in ways that reconstructs its form and function (Yanow, 1996). By recognizing the agency of regulators in the policy process, it becomes apparent that regulation shares much in common with studies of policy implementation. In a basic sense, implementation studies examine the factors that lead to policy success. For example, Pressman and Wildavsky's classic *Implementation* traces a promising policy that gets derailed because of actors with divergent interests, an unclear policy mandate, and a lack of resources and political support. This strand of implementation theory measures implementation based on policy outcomes that can then be used to develop generalizable causal theories to solve policy problems.

The "top-down" perspective further sees policy designers as central actors in the implementation process. Local actors are often viewed as impediments to implementation since the emphasis is on clear and consistent goals that can carry a policy from its enactment to a desired state of affairs (Matland, 1995). In contrast, "bottom-up" approaches to implementation argue that carrying out any new policy or reform entails more than just a well-designed set of policy instructions and procedures. Furthermore, while outcome information about a particular policy is important in and of itself, it does not say much about the programs that produced them (Matland, 1995, p. 147). This approach fundamentally takes issue with top-down and linear models of policymaking that oversimplify the policy process by assuming that ideas lead to enactment and enactment leads to implementation. In the actual working-out of policy on the ground, however, the ideas that went into policymaking are reexamined and reinterpreted. A policy with successful outcomes thus results not from getting first the ideas and then the implementation right, but from groping toward workable ideas (Lin, 2002, p. 37). Lipsky's (1980) main premise in *Street-Level Bureaucracy*, that service deliverers ultimately determine policy, is a major tenet of the bottom-up model. The purposes and values of those who implement policy, which may differ greatly from those of policy designers, have a crucial role in reconstructing what a policy means and how it is executed. A given policy, therefore, cannot be easily described by what exists on paper in a law, a regulation, or an agency memo, but is given form by actors who implement policies.

In this light, regulators have an important role in the policy process by applying broad policy to specific circumstances and cases. Moreover, policymakers cannot anticipate all issues when enacting a policy: unforeseen issues inevitably arise, and market conditions change over time. For example, regulators routinely clarify definitions of what constitutes improper exercise of market power in electricity generation, and contemplate their role and authority in reducing carbon emissions (Bateman & Tripp, 2014; Knee, 2011; Owen, 2008). In fact, while policymakers and government officials design policies, regulators make policy in reaction to matters raised in specific cases or disputes (Brown, 2002). In so doing, they encounter matters that require detailed interpretation of policy or filling in gaps left by policymakers. This is an inherent part of what regulators have to do in order to carry out their mandates. The degree of flexibility in the regulatory process allows regulators to make appropriate incremental changes and avoid undue politicization of relatively minor issues (Brown, 2003). Ensuring that policymaking by regulators is accomplished under the delegation of authority from the state is checked by policymakers who possess the ultimate authority to change policy on a prospective basis. Appellate review also provides a means to contest the legal basis of regulatory decision-making.

The attention to regulatory practice has led scholars to look at what regulators actually do in order to rethink principles for evaluating regulatory agencies. Sociological and governmentality theories particularly associated with Ayres and Braithwaite's (1992) *Responsive Regulation* have centered on how regulatory responses are an essential strategy of market governance. The basic idea of "responsive regulation" is that governments should be responsive to the conduct of those they seek to regulate in deciding whether a more or less interventionist response is needed. The concept also suggests that participation of third party groups in the regulatory process can assure the accountability of discretion. This underlines the view that regulation should be viewed as a process through which regulators consider stakeholder interests (Prosser, 2005). From this perspective, regulatory legitimacy lies in wide participation in decision-making rather than mere technical expertise (Prosser 1999; Hira, Huxtable, and Leger 2005). This approach goes against theories of regulation that advocate for a clearly defined program or a set of prescriptions concerning the best way to regulate. On the contrary, the best strategy depends on context, regulatory culture, and history (Ayres & Braithwaite, 1992, p.5).

2.3. Policy Support Schemes for Renewable Energy

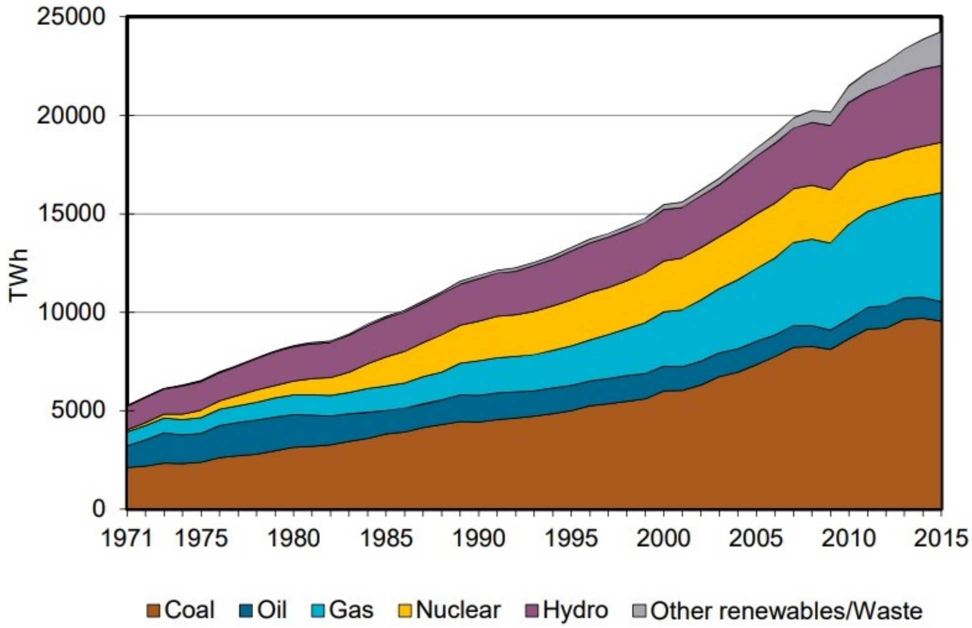
The privatization and commercialization of electric utilities occurred at the same time as governments made greater efforts to increase their shares of renewable energy. According to the U.S. Energy Information Administration (EIA), renewable energy resources are, "energy resources that are naturally replenishing but flow-limited; inexhaustible in duration but limited in the amount of energy available per unit of time" (EIA, 2017). They are not depleted when used. Renewable energy resources for electricity generation include hydro, solar, wind, biomass, geothermal, ocean thermal, wave action, and tidal action. The Organization for Economic Cooperation and Development (OECD) further specifies energy derived from biogases and the renewable fraction of municipal waste as part of its overall definition of renewable energy.[1] Conventional fossil fuels – petroleum, natural gas, coal – are considered nonrenewable because they take millions of years to form and are available in limited supplies. Fossil fuels are the dominant source of energy in the world, contributing about 66% of global electricity production in 2016 (World Bank, 2016).

Internationally, the first oil crisis in 1973 encouraged investments in alternative energy technologies (Nemet, 2009). A greater use of renewable energy sources was seen as one way for governments to reduce their reliance on oil imports. In addition to improving long-term security of supply, environmentally-motivated organizations and initiatives also began to argue for the potential of renewables to address environmental problems and serve as a sustainable alternative to nuclear energy. The environmental movement of the 1970s supported renewables as being less polluting and less likely to contribute to environmental degradation. The *Our Common Future* report, published by the United Nations Brundtland Commission in 1987, further drew attention to the need of reducing air pollution and anthropogenic sources of carbon dioxide (CO2) emissions (Breukers, 2006, p.22; WCED, 1987). In general, governments created policies that stimulated renewable energy sources that were already relatively mature at the beginning of this period, such as large-scale hydropower and certain types of biomass.

[1] In line with this definition, nuclear energy is not considered a renewable source of energy because conventional nuclear fission relies on finite stores of uranium that have been extended only through technological improvements (MacFarlane & Miller, 2007). For a summary of this view, see Jacobson & Delucchi (2011).

Figure 1

IEA Estimates of World Electricitv Generation bv Source



"New renewables" such as wind and solar began to gain a modest proportion of the market in the 1980s. For wind energy, early actors at the national level included the Netherlands, Denmark, Germany, and the United States (Street & Miles, 1996). This first "Wind Rush" centered on investing in large, utilities-scale wind turbines that could be manufactured by firms involved in aerospace technology or agricultural machinery (Heymann, 1999). Over time, wind energy has become the fastest growing renewable energy source in the world. At the end of 2015, wind energy reached a global installed capacity of 487 GW (IRENA, 2016). Countries outside of Europe and North America have emerged as markets for wind power production and domestic manufacturing. For instance, in 2010, China's cumulative installed capacity in wind energy reached approximately 45 GW, which enabled it to surpass the United States and become the world's largest wind market (Ru et al., 2012). Technological advances since the time of the oil crisis have made a range of commercial wind turbines available, including the exploration of offshore and ocean-based wind power.

Beginning in the 1960s, the development of solar photovoltaic technologies increased dramatically as an outgrowth of space exploration. While Japanese and U.S. companies were early leaders in solar PV manufacturing, solar energy lagged behind more mature sources of renewable electricity. In the United States, the enactment of the federal Public Utility Regulatory Policy Act (PURPA) and the Energy Tax Act (ETA) in 1978 spurred the creation of new utility-scale solar and wind electricity systems which encouraged homeowners to invest in energy conservation and solar technologies through tax credits. Germany joined this momentum for solar energy in the mid-1980s. A national feed-in tariff program guaranteed grid access to renewable energy power producers as well as long-term price guarantees for the electricity they generated, spurring global cost reductions for solar. The boom of the solar cell industry in China and Taiwan in 2006 has driven prices down even farther. Today, China produces more than two thirds of the world's PV – more than the United States, Japan, and Germany combined (Brown, 2015).

Once viewed merely in terms of the environmental movement, renewable energy technologies have made considerable progress in substituting fossil fuel-based sources of electricity. Not all alternative energy technologies, however, are commercially mature or have reached adequate levels of economic performance. In part, this is because renewable energy has confronted a variety of economic, regulatory, or institutional disadvantage relative to other forms of energy (Beck & Martinot, 2004, p. 366). A common economic argument is that the full social costs of greenhouse-gas emissions are not reflected in current market prices for fossil fuels. This "mispricing" of fossil fuels suppresses the demand for technological substitutes for fossil fuel technologies. In addition, incumbent technologies have benefitted from past R&D subsidies and other forms of government support. The mass production and extensive operating experience with these technologies has reduced uncertainties about their performance and reliability (Menanteau, Finon, & Lamy, 2003, p.800; Mowery, Nelson, & Martin, 2010, p. 1013).

2.3.1. Comparing Renewable Energy Policies

A growing objective among governments has been to create a more level playing field for renewable energy technologies. The liberalization of electricity markets was originally thought to provide the necessary opportunities to create competitive markets for renewable energy. In theory, energy producers, suppliers, and consumers would have more freedom to choose between different types of electricity. Consumers would no longer be bound to one supplier, and those who wanted to pay for an "environmental good" could purchase green electricity directly from renewable energy producers. The experimentation with energy market liberalization in United States, Germany, and the Netherlands, however, has shown that consumers' willingness to pay for renewable energy is relatively low (Menanteau, Finon, & Lamy, 2003, p.800). In case studies which have allowed consumers to purchase renewable energy, the proportion of green electricity purchases is around 2-3%, except in situations where there are strong incentives in the form of tax exemptions (Jegen & Wüstenhagen, 2001). These experiences suggest that individual choices do not fully reflect the real value that the public may place on developing renewable technologies.

Since market forces cannot guarantee the development of renewable technologies, a number of policy instruments have been formulated. Financial instruments, such as tax credits and loans with below-market interest rates, have been used to provide incentives for renewable energy by reducing the costs of such investments (Olmos, Ruester, & Liong, 2012). Notably, an ongoing debate has centered on "demand-pull" and "technology-push" policies (Nemet, 2009; Peters et al, 2012). Demand-pull policies aim to increase the market demand for renewable electricity through subsidies and other financial incentives, and in turn spur further innovation. In contrast, technology-push policies are supply-driven and are meant to foster technological options by directly supporting research in science and technology. Influenced by the success of "Big Science" in the 1940s,[2] the core idea is that advances in scientific understanding determine the rate and direction of innovation and satisfy market needs. The balance between demand-pull policies and technology-push policies has strongly shifted toward demand-pull in recent years (Hoppmann et al., 2015), although a general agreement exists that promoting specific combinations or "policy mixes" from both of these categories is needed (Peters et al., 2012).

The decision to design policies based on setting prices or quantities forms the backbone of demand-pull policies. In the case of price-setting policies, favorable pricing regimes are established for renewable energy relative to other sources of generation. The quantity of investments obtained under such regimes is unspecified, but prices are stated in advance. Feed-in tariffs (FITs) are common price-setting mechanisms which provide developers with long-term power purchase agreements for the sale of their electricity. These purchase agreements typically offer a specified price for every kilowatt-hour (kWh) of electricity produced and are structured by contracts ranging from 10-25 years (Klein, 2008, Lipp, 2007). In the United States, the Public Utility Regulatory Policy Act was the first program to use of a feed-in policy that required electric utilities to purchase renewable electricity at the projected wholesale or "avoided cost" of conventional or fossil fuel-based electricity (Martinot, Wiser, & Hamrin, 2005). Countries such

[2] ''Big Science'' refers to government investment in science and technology which began in the 1940s, led by the United States. Technical change was seen as a process in which scientific discoveries automatically led to useful applications that satisfied market needs.

as Denmark, Italy, Austria, France, and Netherlands have adopted feed-in tariffs as their main electricity support schemes, combined with quota obligations or other tax incentives (Haas, et al., 2011). The cost of subsidizing producers is covered either through cross-subsidies among all electricity producers, taxpayer monies, or a combination of both systems to share the burden more equitably (Menanteau, Finon, & Lamy, 2003, p.802).

In contrast, quantity-forcing policies define a certain percentage or amount of renewable electricity to be developed. The final price for the electricity generated is then decided in the marketplace. The two main quantity-forcing policies are renewable energy obligations and energy auctions, also known as competitive bidding or tendering schemes (Beck & Martinot, 2004, p. 370; Bergek & Jacobsson, 2010). Renewable energy obligations require a minimum share of renewable energy in the electricity supply. Obligated utilities must ensure that targets are met either through their own generation, renewable energy purchases from electricity producers, or direct sales from third parties to the utility's customers (Beck & Martinot, 2004, p. 372). Early national examples of energy targeting in Europe include national legislation, such as the United Kingdom's Renewables Obligation (RO) (Haas et al., 2001; Reiche & Bechberger, 2004). In the United States, Renewable Portfolio Standards (RPS) have been widely used by state governments to encourage the deployment of renewable energy (Rabe, 2004; Wiser, Barbose, & Holt, 2011).

2.3.2. Energy Auctions

While feed-in tariffs have been the most common support mechanism for renewable energy, auctions have gained popularity and have been implemented in over 60 countries, including Brazil (Ferroukhi, Hawila, & Vinci, S, 2015). An energy auction is a type of quantity-based policy that is used to procure renewable electricity. To carry out an auction, the government typically issues a call for tenders to procure a certain capacity or generation of energy. Project developers who participate in the auction typically submit a bid with a price per unit of electricity at which they are able to realize the project. The auctioneer evaluates the offers on the basis of the price and other criteria and signs a power purchase agreement with successful bidders until the targeted level of electricity is reached. The auction winners are guaranteed the purchase of their renewable electricity for a specific period of time at the pay-as-bid price. The United Kingdom's Non-Fossil Fuel Obligation (NFFO) scheme, introduced in 1989, pioneered the usage of this type of mechanism. Early auction schemes also existed under France's Eole program to promote wind energy (Menanteau et al., p.802).

The debate on the relative advantages of auctions versus other policy options generally centers on costs, ease of implementation, and technological innovation. Unlike feed-in tariffs, which have proven to be costly in terms of subsidies payments to producers, an advantage of competitive bidding procedures is that they can lead to rapidly declining prices for renewable energy. The level of subsidies for renewable electricity generation can be controlled, where the organization of successive tendering procedures progressively reveals the shape of the cost curve for renewable electricity. In general, auctions are advanced as encouraging technology cost reductions (Beck & Martinot, 2004, p. 371), while reducing support payments to incentivize renewable energy (Menanteau et al., 2003, p.807). Several mature renewable energy markets, including Germany, Japan, and the United Kingdom, have transitioned from FITs to using competitive procurement as a way to remedy subsidy budget deficits, high costs, and managing market saturation. Similarly, emerging markets have used auctions to procure cost-competitive renewables without subsidies (Munsell, 2017).

Despite the positive features of energy auctions, a major criticism is that competing participants bid below their true costs in order to secure contracts. After an auction has taken place, project developers are at times unable to meet the terms of the bid or end up insolvent (Beck & Martinot, 2004, p. 370), where project delays have also been a recurring concern. Specific to auction mechanisms, participants frequently engage in speculative strategic behavior by underbidding. This occurs when an auction participant submits an unprofitable bid price either knowingly or due to lack of experience. Bidders may seek to strategically influence the auction results through deliberate underbidding in order to increase their chances of winning, or when they have underestimated their own project costs (i.e., the "winner's curse").

As a result, contracts awarded to low bidders do not always translate into projects on the ground, creating higher administrative costs for the organizing agency. For example, implementation rates of the Non-Fossil Fuel Obligation (NFFO) in the UK between 1990 and 1998 were at 38% of selected projects and only 26% of the contracted capacity. Similarly, in France and Italy, more than half of auctioned projects in solar and wind energy had not been finalized by their deadlines (Gephart, Klessmann, & Wigand, 2017). Moreover, in comparison to feed-in tariffs, energy auctions are argued to offer fewer incentives for technological innovation that enable manufacturers to invest more heavily in R&D. The prevailing policy concern, however, is whether auctions can effectively deliver targeted deployment levels as experience shows that winning projects may not always be implemented.

The existing literature on energy auctions argues that observed weaknesses of auction schemes can be remedied by design choices. The goal is to identify and eliminate specific fail factors in auction designs in order to improve auction implementation rates. Typical fail factors include general risks related to project development and undesirable strategic behavior, namely underbidding (Gephart, et al., 2017, p.151). Risks related to project development are not unique to auctions but exist for all policy support schemes for renewable energy, such as not obtaining planning consent or not having transmission lines to connect a project to the grid. A project developer may also lack sufficient experience which can result in unexpected cost increases and make the project economically infeasible.

To correct these problems, the literature almost exclusively focuses on auction design elements to increase implementation rates. These design principles attempt to ensure that auction winners will deliver awarded projects. Common to most auction designs are material qualification requirements which require that participants provide evidence of planning consent and grid connection agreements in their project proposals. Other qualification requirements include proof of a bidder's financial or technical capability. This includes "bid bonds" that need to be submitted together with the bid and which are reimbursed after project completion. Technical capability can mean providing evidence, for instance, of a certain amount of years of experience in developing similar projects. Predefining the period until project completion is another design element that is combined with qualification requirements and penalties to improve the effectiveness of an auction. Lastly, financial and non-financial penalties address the risk of unwanted strategic behavior by penalizing the non-implementation or delay of projects (Gephart et al., 2017, p.153).

While the literature identifies factors that can influence auction success, there is little empirical evidence which shows how changes to design elements affect market outcomes. In part, there is less information about the long-term performance of renewable energy auctions since they have not been in operation as long as conventional feed-in tariffs and other support mechanisms. A combination of theoretical insights and empirical examples suggests that the use of penalties and planning consent are important design elements that can improve the delivery of projects (Toke, 2015). For instance, Anaya and Pollitt (2014) comment that the absence of penalties was a factor in the failure of the United Kingdom's Non-Fossil Fuel Obligation (NFFO) in the 1990s. Bayer et al. (2018) found that changes to auction designs in Brazil reduced project delays due to transmission grid issues. However, since the financial risk for transmission delays was transferred to the project developer in future auctions, the bidding price included an additional risk premium. In general, a drawback to enforcing higher implementation rates is increased risks for bidders, which can in turn increase auction prices (Gephart, et al., 2017).

Furthermore, the literature rarely discusses circumstances in which auction design changes have a negligible effect on mitigating project delays and non-delivery. In cases where options to alter auction design are limited, studies tend to focus on quality of project management. For example, to ensure access to a reliable supply of equipment, project developers can sign binding supply contracts before an auction occurs. However, supply problems can also arise due to the bankruptcy of commissioned equipment suppliers. These cases are beyond the control of the project developer and cannot be prevented by an advanced auction design (Bayer et al., 2018). Other policies that lie outside the auction design are not addressed, or are assumed to be secondary factors. For example, processing times for environmental licenses have historically caused significant delays for energy projects (Hochstetler, 2011), and for auctioned wind energy in particular (Nation Research Council, 2007). The literature focuses on improving outcomes directly through the auction process, rather than exploring the extent to which other policies facilitate or hinder implementation.

2.3.3. Distributed Generation and Net-Metering

The traditional way to support renewable energy has been to offer financial incentives to construct renewable energy facilities. Examples of these incentives include aforementioned price and quantity-based mechanisms, research and development grants, and tax credits. Another popular incentive has been to support renewable electricity through distributed generation. Distributed generation – the production of electricity at or near the location where it is consumed – does not apply to only renewable energy, but can strongly influence renewable energy investments (Beck & Martinot, 2004, p. 380).[3] Globally, the growing use of distributed generation has been a major driver of solar energy produced by photovoltaic panels (IEA, 2017a). Most systems are "grid-tied" and are connected to the distribution and transmission network. They send their excess electricity back to the utility to be used by other customers. Some distributed generation systems are not connected to a utility's power grid and are thus considered "isolated." This requires that distributed generation systems operate synchronously with the electric system, making them subject to certain operational and equipment requirements usually specified in an interconnection agreement or energy tariff (Lazar, 2016).

The use of distributed generation systems raises important question for how systems owners should be compensated for the electricity they sell to the grid. A common pricing scheme is referred to as "net-metering." Under this approach, the distributed generation customer's meter "runs forward" to purchase electricity when less power is produced than needed. When a distributed generation system produces more power than is needed, the meter "runs backward" and sends the excess power to the grid. At the end of the billing period, the customer is billed for the net power used at the retail electricity rate, which is the volumetric rate a residential customer

[3] Most customer-sited generation is "behind the meter," which means that it operates on the customer's side of the utility's meter.

pays per kilowatt-hour (kWh) of electricity. In practice, there are significant variations among net-metering compensation programs. The way that a net-metering framework is designed significantly influences the profitability and viability of on-site energy generation. Net-metering policies are often revised to take into account utilities considerations, such as special fixed charges for net-metering customers and a buy-back price below the retail price of electricity (Revesz & Unel, 2017).

Utilities companies, which play a key role in the transmission and distribution of electricity, have attempted to slow the growth of distributed generation. When distributed generation represents a small percentage of overall electricity production, it poses little threat to the utilities' model and profits. As more customers adopt distributed generation systems, which is the current trend globally, the amount of electricity they sell decreases. This reduction in earnings further means that utilities have fewer financial resources to cover the costs to maintain and operate the grid, commonly referred to as stranded investments. As a result, utilities have frequently supported legislation that reverses policy support for solar energy and distributed generation (Hess, 2016).

2.4. Energy Transitions and Technological Change

Scholars have increasingly used the term "energy transitions" to refer to the transformation of fossil fueled-based energy regimes to ones with greater shares of renewable energy.[4] Rather than limiting the analytical focus to individual policies, the concept emphasizes that efforts to reduce carbon emissions and diversify energy supplies must be understood in connection with the institutional systems in which new policies are developed. In particular, the

[4] Bridge et al. (2013) note that, although "energy transition" and its implication of a change in conditions is clear enough, there is no consensus on a desired end state. Furthermore, while the concept is commonly associated with energy production, it can also encompass patterns of consumption and energy use.

technical change and innovation systems (TIS) and multi-level perspective (MLP) frameworks are widely used to study the dissemination of renewable energy technologies (Geels, 2002; Verbong & Geels, 2007; Jacobsson & Johnson, 2000). While these frameworks differ in several respects, they both ground their analyses in the concept of a *socio-technical regime* (Hughes, 1983), in which previous technological choices, institutions, and engineering practices have resulted in a dominant or "normal" way of doing things (Carlsson & Stankiewicz, 1991; van Eijck & Romijn, 2008, p.312). In this way, the established energy system and associated institutional framework often prevent the adoption of potentially superior alternatives (Foxon, 2002; Unruh, 2000). Actors must thus change the institutional setting to create space for renewable technologies which have suffered economic, regulatory, and institutional disadvantages relative to other forms of energy (Beck & Martinot, 2004).

The TIS perspective focuses on the processes through which a new technology emerges and is diffused (Bergek and Jacobsson, 2003; Jacobsson & Bergek, 2004; Markard & Truffer, 2008). This framework emphasizes that the co-evolution among physical technologies and institutions is responsible for the relative stability of a socio-technical system (Unruh & Carrillo-Hermosilla, 2006). As a result, a new technology may suffer a disadvantage from incumbent technologies that have been able to undergo a process of increasing returns (Arthur, 1988). This tends to associate the new energy technology with a higher market price based on lack of scale, inexperience, and a set of institutions which are culturally biased to favor existing technologies. In this sense, "cost" and "market failure," traditional concepts influenced by neoclassical economics and that are used to assess innovation policy, are not necessarily the factors that hinder the development of a new technology. Since institutions have established practices that favor incumbent technologies, they block the introduction or expansion of alternative options (Jacobsson & Johnson, 2000, p.633; Jacobsson & Bergek, 2004, p. 817).

The TIS approach further attempts to delineate the actors and structural elements in a given energy-based technological system. Common actors within a technological system are firms and manufacturers of specific technologies. For example, in the case of solar cells, these include firms that manufacture machinery to make thin film solar cells, engineering firms designing and delivering solar installation systems, and electricians and architects. "Networks" of actors constitute important channels for the transfer of both tacit and explicit knowledge. Technological and policy networks may be built around markets and may therefore be conducive to the identification of problems and the development of new technical solutions (Jacobsson & Bergek, 2004, p. 818; Rao, 2004; Smith, 2000). Together, these actors can create powerful political forces to lobby on behalf of a given technological system (Unruh, 2000, p. 823).

In socio-technical systems designed by and for specific technologies, institutions stipulate the rules and norms that regulate interactions between actors and technologies (Edquist & Johnson, 1997; Jacobsson & Bergek, 2008, p. 818). The legitimacy of a new technology and its actors, their access to resources, and the formation of markets are strongly dependent on the institutional framework. If the framework is not aligned with the qualities and needs of the new technology, it may be blocked from being adopted. The process of institutional change is characterized as a struggle in the political arena between proponents of the new and incumbent technological systems. The centrality of institutional alignment implies that actors in rival technological systems not only compete in the market for goods and services, but also try to gain influence over the institutional framework (Jacobsson & Johnson, 2000, p.631).

The TIS approach attempts to delimit analytically the borders of an energy system. By arranging empirical material in terms of functions within a system, it seeks to trace the way through which a particular combination of actors or a specific institutional set-up shapes the generation, diffusion, and utilization of a new technology (Jacobsson & Bergek, 2004, p. 819). Moreover, drawing on the literature on product and industry life cycles, the transformation of the energy system is generally characterized by two main phases: a formative period and one of market expansion. With respect to the formative period, the newness of the technology presents entrepreneurial actors, investors, policy-makers with high levels of uncertainty. A market for the technology may not exist or be underdeveloped. "Niches" or "nursing markets" are normally required so that actors can learn about the characteristics of the new technology and expectations can be formed (Erickson & Maitland, 1989; Kemp et al., 1998). The formative stage is also marked by the establishment of networks with the objective of shaping the institutional architecture. For a new technology to develop, technology-specific coalitions and networks need to form and gain influence over institutions. One way is that coalitions argue that a particular technology is a solution to wider policy concerns (Bergek, Hekkert, & Jacobsson, 2008, p.22-23; Jacobsson & Bergek, 2004, p. 821-822).

Following a formative stage, the TIS framework contends that government support and investments generate a system which can sufficiently "change gear" and grow in a self-sustaining way. The expansion of markets and institutional alignment propel the new technology in a process referred to as "cumulative causation." TIS studies that focus on the learning aspects of technological change also liken this stage of development to systems concepts of "dynamic loops" and "circular processes." A successful deployment program is one which initiates a technology learning process that brings down costs and improves technological performance (Wene, 2008).

The multi-level perspective takes a broader approach than TIS theory. Developed by Dutch researchers interested in applying socio-technical theory to government energy policy, the MLP posits three levels for understanding energy transitions: a landscape (macro) level that encompasses the dynamics of deep cultural, economic and political patterns; a regime (meso) level that refers to the current practices, routines and dominant rules that prevail in a socio-technical system; and a niche (micro) level which represents the space where actors experiment with radical innovations that may challenge and break through into the prevailing regime (Geels, 2002; Eijck & Romijn, 2008; Verbong & Geels, 2007). Unlike the TIS approach, the landscape is an important analytical level which externally conditions the interaction of actors and their decision-making. While regimes refer to rules, regulations, and technical infrastructures that enable and constrain activities, the landscape refers to wider, technology-external factors. These include oil prices, economic growth, war, and environmental problems (Geels, 2002, p.1260). For example, internationally, the first oil crisis in 1973 was an important landscape factor which encouraged governments to reduce their reliance on oil imports and invest in alternative energy sources.

In line with the TIS perspective, niches have important functions as innovative spaces which are insulated from “normal” market selection in the regime, acting as “incubation rooms” for radical novelties (Geels, 2002, p.1260; Schot, 1998). The importance of early markets for learning processes is a fundamental concept among approaches to energy transitions (Kemp et al., 1998). In the initial state of niche formation, experiments with a new technology tend to be few and isolated. The principal aim of niche learning is to reduce uncertainty about future socio-technical development. Once this has been achieved, and a promising technical design has been developed, a “technological niche” is said to have been created (Eijck & Romijn, 2008, p. 312). From the MLP perspective, niches are crucial for technical change because they provide a means for change and open up new pathways for socio-technical regimes.

These three levels form a nested hierarchy. Regimes are embedded within landscapes, and niches within regimes. A distinct feature of the multilevel perspective is that the success of a new technology is not only governed by processes within the niche. In comparison to TIS, which focuses on technological systems, the specific innovation activities in niches are linked to large-scale transformations at the regime and landscape levels (Essletzbichler, 2012, p. 795). Developments at the level of the existing regime and the sociotechnical landscape reinforce or hinder processes within the niche to determine if an opening for new technologies will occur. Radical innovations break out of the niche-level when ongoing processes at the levels of the regime and landscape create a “window of opportunity.” This analysis of niche, regime, and landscape change to explain transitions offers a perspective of how new socio-technical regimes rather than a single technology or sector emerges and eventually becomes dominant. Landscape factors that exert pressure on the regime can serve as an overarching source of technological change.

Scholars have used the TIS and MLP frameworks to analyze the diffusion of renewable energy technologies (Bergek & Jacobsson, 2004; Foxon, 2007; Jacobsson & Lauber, 2006; Kern & Smith, 2008). Government policies and support schemes are often studied for their role in inducing the dissemination of renewable energy technology. For instance, Bergek and Jacobsson (2003) examine the growth of the German, Dutch, and Swedish wind turbine industries. They identify several factors contributing to the relative success of the German industry, including the creation of technological diversity in an early phase of development, the establishment of social legitimacy for wind energy, and the use of advanced market creation policies in a later phase. Foxon and Pearson (2007, 2008) have closely studied improvements in UK low-carbon energy policy through an innovation systems lens. They emphasize the importance of widespread social acceptability in sustainability innovation, particularly a shared vision between government, industry and the research community for each sector, as well as the need for policy incentives to overcome specific system failures (Foxon et al, 2005, p. 2135).

2.5. Renewable Energy and Regional Policy Development

The application of energy transitions frameworks has advanced our knowledge of how the transformation of energy systems and institutions takes place. The literature's early focus on national energy policies, however, have made it vulnerable to criticisms (Bridge et al., 2013; Truffer & Coenen, 2012). A major criticism is that such studies focus on the deployment of specific technologies without explicitly considering the role of space or geography in technological change. For example, the TIS framework seeks to include all relevant actors in the diffusion of an energy technology in order to address national-level policy concerns. The fact that many provincial and sub-provincial governments have created renewable energy policies is not a central concern. Despite taking into account major historical shifts in energy systems at national and global scales, contemporary work on low-carbon energy transition has paid only very limited attention to questions of scale and space (Bridge et al., 2013, p.332).

Several contributions have outlined how energy systems and technological change processes are constituted spatially. Responding to the European Union's restructuring of national and transnational policy processes, the multi-level governance perspective has drawn attention to the changing relationships between different levels of government in carrying out energy policies and highlighted instances where regions and subnational governments have exercised wider authority and autonomy (Bulkeley & Newell, 2010; Cowell, 2017; Smith, 2007). For example, Smith (2007) analyzes the regional dimensions of multilevel governance structures in England. She differentiates between "Type I" and "Type II" forms of renewable energy governance: the former emphasizes top-down commits for regionalization, while Type II commitments are less formal and more "soft," and regional government try to exercise wider authority and autonomy. Multi-level studies tend to focus on the changing relationships between different levels of government rather than the causal relationships between regional drivers and increases in renewable energy sources.

Urban studies in particular has demonstrated the strategic role of cities and regions in creating policies to promote renewable sources of energy. Several contributions have outlined the different roles that cities hold in transition processes (Bulkeley et al., 2011; Hodson and Marvin, 2010, 2012; Rutherford & Coutard, 2014). Hodson and Marvin (2012, p.424) characterize cities as "an actor in its own right, a niche for experimentation to think about new ways of organizing relationships between energy producers, consumers and flows through the city." Geels (2011, p. 14) stresses that cities can either be primary actors and seedbeds of national transitions, or play a limited role.

Prevalent energy transitions frameworks have also been adapted to analyze local and regional processes. Economic geography and studies of industrial clustering have long recognized the significance of regional institutions in contributing to the development of new technologies and markets (Saxenian, 1994; Storper, 1995), providing infrastructure, spillovers of knowledge associated with proximity to universities, and specialized input suppliers and services. Scholars have increasingly drawn on this literature to provide conceptual clarity to energy transitions research. For example, Coenen et al. (2010) explore how geographical proximity explains why certain niches evolve and to what extent local experiments influence the wider institutional framework. In a similar way, Mattes et al. (2015) couple the TIS approach with literature on regional innovation systems to analyze policy developments in two regional "subsystems" in Germany. They emphasize the importance of informal, personal networks and the limited number of political actors involved in local energy decision-making. Collectively, these studies offer productive insights for explaining how energy choices and outcomes are shaped in particular places.

Studies on environmental and climate politics provide further insights into how regions can set agendas in policy implementation. They have shown how governments often carry out policies that have been developed at the federal level, but can also take policy action when the government has not decisively acted on an issue (Bulkeley & Betsill, 2003; Schreurs, 2008). Rabe (2004a; 2004b) demonstrates that issue framing can shed light on why state governments in the United States enact climate change policies, which are heavily driven by renewable energy policy. He claims that states have framed their different policy reactions in one of three ways: as a response to an environmental threat, as a response to an economic development opportunity, or as a response to an economic threat. "Policy entrepreneurs" contribute directly to issue framing by cultivating new policy ideas. They tend to be located in state government agencies, including those devoted to environmental protection or energy, and have often developed reputations as policy experts. They frequently draw upon their previous experience to frame policy proposals as economic opportunities (Rabe, 2004a, p. 31). While broader economic and political institutions structure energy and environmental policies, individual action plays a role in mobilizing policy activities to support new initiatives (Agassi, 1975).

2.6. Contributions to the Literature

The standard model for electricity reform frames regulatory bodies as strictly economic institutions. In practice, political pressures and social concerns do not go away after electricity restructuring (Dubash, 2005). Since regulatory agencies operate at the intersection of both political and private sector influences, striking the right balance is both critical and politically challenging. Regulators have authority and discretion in carrying out government policy, and consequently have opportunities to shape their mandate and institutional culture in ways that support renewable technologies. Building on insights from energy transitions research, regulations form part of the wider institutions and cultural practices that can perpetuate the status quo (Unruh & Carrillo-Hermosilla, 2006), but which can serve as crucial sources of system transformation. The regulatory process can also realign actors into new coalitions that disrupt existing policy practices (Smith & Kern, 2007). Renewable energy auctions and distributed generation regulations provide excellent cases with which to examine how the "politics of regulatory policy" influences renewable energy development.

By first setting the backdrop for wind and solar policies, this dissertation demonstrates that new energy technologies do not enter into empty terrain. Instead, they must compete with pre-existing technologies: "history matters" in that new technologies have to adapt to previous investment and policy decisions, often made decades in the past. Therefore, pre-existing infrastructure, both physical and institutional, can create important and lasting constraints (del Río & Unruh, 2007). Chapter 4 accounts for the co-evolution of hydroelectric infrastructure and current arrangements in the Brazilian electricity sector. It underlines how the frequently path-dependent nature of technological and institutional frameworks condition the adoption of wind and solar technologies.

Turning to the case of wind energy, there is surprisingly little research on how the regulatory context affects the implementation of energy auctions. In restructured power sectors, regulatory agencies frequently serve as the auctioning authority and interact directly with project developers. While the literature on auction design cites the importance of independent regulators in setting market rules and enforcing contracts, there are few studies on how regulatory institutions influence auction implementation (Bellantuono, 2016). This might be because the literature assumes that an auction design can adapt to the specifics of each power system. It is presumed that an auction can internalize context-specific factors, such as a government's policy objectives, the degree and nature of competition in the electricity market, the variety of technologies available, and the existing regulatory and institutional frameworks in which investors operate (Maurer & Barroso, 2011, p. xvi). Observed increases in implementation rates are generally attributed to successful amendments to an auction design.

This research does not discount previous analyses that have found that auction design changes can improve implementation outcomes. What is missing from this literature, however, is recognition that the success of renewable energy auctions also depends on their ex-post implementation. The effectiveness of auctions to deliver projects ultimately depends on ensuring compliance from market participants. Compliance and enforcement of rules are not a given, nor can they be captured within an auction design, but result from the regulatory process. Regulators also work with stakeholders in ways that support the credibility of regulatory solutions. This dissertation shows how regulatory approaches to compliance and collaboration are important policy processes that lie outside of auction designs for wind energy.

The development of a net-metering program for small-scale energy systems further illustrates how regulations can enable technological change. The energy transitions literature refers to regulations as generally protecting the status quo and being responsible for technological lock-in (Unruh, 2000). Institutions are considered important insofar as private actors and firms can overcome regulatory and institutional barriers to open space for new technologies. The second part of Chapter 5 provides insights into the relationship between energy transitions and regulatory agencies. It describes how energy regulators have prioritized the adoption of distributed generation technologies in Brazil. In a system designed for large-scale hydroelectric power, regulators' support for small-scale generation technologies powered predominately by solar photovoltaics fundamentally questions the underlying institutional arrangements in the electricity sector and serves as an important source of technological change.

Lastly, there is little attention to how states and regional governments in Brazil have influenced federal decisions about supply planning and energy diversification, or how they set policy agendas that contribute to the learning and development of renewable technologies. Moreover, regional differences in renewable energy investments are attributed to physical advantages, such as high winds speeds and solar irradiation. While natural resource potential is important, it must be understood in terms of the context in which renewable technologies are developed and deployed. Paraphrasing Meadowcroft (2009), their fates are bound up with different energy options. In elaborating on this view, chapter 6 aims to build on previous studies that demonstrate under what conditions states and regions have opportunities to guide the formation of renewable energy markets.

Chapter 3

Research Design and Methods

A qualitative research design was used to examine how regulatory reforms, institutional changes, and state-level policies impact the development of renewable energy sources in Brazil over the period of 1992-2017. This research sought to discover (1) how electric power reforms and regulations have influenced the development of wind and solar energy to date and (2) to explain how the various planning and policy approaches taken by state governments affect renewable energy development. The fieldwork activities included semi-structured interviews and document collection. To overcome a "national bias" in the literature, which prioritizes the nation-state as a unit of analysis, the states of São Paulo, Pernambuco, and Rio Grande do Norte were selected as comparative case studies to illustrate how renewable energy policies are implemented at a regional scale. The case study method is the most appropriate means to carry out this research because it can explain how and why things happen in certain policy contexts (Ragin & Becker, 1992).

For the purpose of this study, "renewable energy" is restricted to the electricity production sector (also exchangeable with the terminology "supply" or "generation"). It pertains only to electricity generated from renewable resources, including hydropower, wind, solar, and biomass. This dissertation does not directly study non-electricity energy that forms part of the broader energy supply, such as fuel substitution by "cleaner" alternatives in the transport sector. The term "regulatory agency" refers to the government body formed or mandated under the terms of a legislative act to ensure compliance with the provisions of the act, and in carrying out its purpose. "Regulation" is thus understood to mean the policies and actions undertaken by this appointed agency or body to co-manage the electricity sector, not to government intervention in a general sense.

3.1. Plan of Inquiry

The broad framework of critical realism informed the epistemological position of this research project. Combining explanation and interpretation, critical realism emerged in the 1970s and 1980s as a philosophical position to develop a properly post-positivist social science (Archer et al., 1998; Sayer, 1992). Critical realists hold that is possible for social science to refine and improve its knowledge about the real world over time, and to make claims about reality which are relatively justified, while still being historical, contingent, and changing (Archer et al., 1998). This study made realist assumptions to the extent that participants were approached as containing institutional knowledge of policies or programs in the electricity sector, where their "accounts [were] treated as providing insight into their psychological and organizational lives outside of the interview situation" (King, 2004, p.12). Such assumptions were employed to systematically compare different stakeholders' observations with other sources such as government documents and newspaper articles. In the constructivist vein of critical realism, however, this study approached causation critically. Systematic data collection and analysis was meant to establish a robust account of structures and processes to highlight the complexity of actors and organizations which contribute to changes in energy policy, in order to arrive at inferences regarding causal processes.

In accordance with critical realism and other post-positivist stances, this study drew on "grounded theory" as a basis for guiding data collection and analysis. The principles of grounded theory are designed to develop a well-integrated set of concepts that provide a theoretical explanation of social phenomena under study, where it is the researcher's responsibility to catch the interplay of actors responding to changing conditions and the consequences of their actions (Corbin & Strauss, 1990; Creswell, 2014). Grounded theory does not outright reject the canons of "good science," such as significance, generalizability, reproducibility, precision, and verification, but rather aims to make standards and procedures of any research method explicit.[5] Following procedures in grounded theory, the selection of study participants was designed to provide a balanced perspective of actors and to identify as much variation as possible in what methods were being employed to facilitate or prevent the use of new alternative sources of energy at the national and sub-national levels.

I received approval to conduct anonymous interviews from the Institutional Review Board on May 5, 2014 (see Appendix C). To ensure candor and the anonymity, I excluded all names. Interviewees are referred to in terms of general positions within their organizations.

3.2. Interviewing Policy Elites

In conducting qualitative research, the role of the researcher as the primary instrument for gathering data necessitates the identification of personal values, assumptions, and biases. The investigator's contribution to the research setting can be useful and positive rather than detrimental (Locke et al., 1987). While I am fluent in Portuguese and have lived in Brazil for more than two years cumulatively, I am foreign and American, and thus I was perceived differently than Brazilians from the point of view of interviewees as well as the "gatekeepers" who deny or provide access to them. This placed me in a privileged position at times. I was often granted access to high-level policy-makers whereas Brazilian researchers investigating similar

[5] More precisely, according to Corbin and Strauss (1990): "Every mode of discovery develops its own standards – and canons and procedures for achieving them. What is important is that all of these are made explicit" (p. 5).

topics have reported not being granted such interviews.[6] One participant who is an executive at a solar installation company explicitly mentioned that he accepted my interview invitation because of my nationality and the prestige associated with my university in the United States.

In general, I found that potential participants from the private sector were less accessible than those from the public sector. Specifically, I encountered more reluctant administrative secretaries and press liaisons who were unwilling to concede an interview on behalf of their associates. The two reasons given were that their employees were only allowed to focus on the work of their organizations, and that their agendas did not permit an interview unrelated to their work tasks. I also found it very difficult to gain access to professionals who worked directly in the oil and gas industry. In the end, I was only able to interview one employee from Petrobras. Upon arriving to the interview site, I was told that I was not allowed to record the interview and instead had to take copious notes during and following the interview.

While my status as a non-Brazilian student researcher sometimes presented challenges when negotiating the interview relationship, it also worked in my favor. During the interviews, I often felt that participants spent considerable time summarizing and providing narratives of policies and institutional histories with which I had already gained familiarity. At times this was helpful, especially in the preliminary stages of data collection when I needed more information on certain policies or events. Further, it was also hard to know what was relevant to answer my research questions in the early interviews, and at that time it was better to have more rather than less information from my interviewees. Moreover, asking an interview participant to explain a policy or program in "her own words" served as a way to gauge institutional priorities, loyalties, and biases. The way that a representative from a utilities company explained net-metering and

[6] For example, in his qualitative case study of Rio Grande do Norte's wind sector, Neto (2013) states that neither the Ministry of Mines and Energy nor Aneel granted him an interview. Neto mentions, however, that he had requested a phone interview, which could have made policy-makers more reluctant to speak with him.

renewable energy regulations differed greatly from solar energy advocates' explanations of the same programs which, in part, reflected the various interests at stake in the regulatory process.

Difficulties arose, however, when participants continued to develop a topic at length without providing new material. While the interviews were semi-structured, my general objective as an interviewer was to have the interviewee provide me with her perspective on the topics outlined in the interview guidelines, in an attempt to balance both depth and breadth in responses. In situations when I judged that the participant had provided sufficient information, I decided that it would have been against social and professional etiquette to interrupt participants and possibly disturb the rapport that we had (Weiss, 1994), however tenuous. My main approach was to redirect rather than discourage the respondent during a pause. Similarly, when interviewees would conclude a response by asking me if they had provided enough information on a particular subject, I would use these openings to redirect the conversation to an underdeveloped or new topic. Also, once I showed a policymaker or official that I knew the basics of a policy, they would move on to something new or reveal a personal opinion.

At the same time, my point of reference as an outsider was an advantage because it allowed me to ask questions that someone with insider status would be assumed to already know, or perhaps would not perceive as significant. For instance, as I progressed with my interviews, I began to notice a pattern. Several participants prefaced their responses by describing Brazil's hydropower legacy, expounding on the low carbon emissions and the degree of energy independence provisioned by their hydropower base compared to other countries that continue to be subject to the geo-political vulnerabilities related to fossil fuels. As an outsider, I was neither professionally nor "emotionally" tied to the symbolic value of the country's hydroelectric development as a case of national success, nor did I take for granted the commonly accepted view that hydropower should be expanded within the electricity supply. Contrary to many professionals in the industry, I sought to challenge this conventional wisdom and elaborate on the notion that a strong dependence on one form of electricity alone could present policy problems. Namely, I stressed that a dominant energy technology could block the inclusion of other renewable and socially beneficial energy sources, and that this could further prove to be an interesting example of how energy transitions are hindered by well-established socio-technical arrangements that are often unquestioned.[7]

Lastly, my personal experiences shaped my perception of issues and activities in the Brazilian energy sector. I was a visiting research scholar and Fulbright Fellow in the interdisciplinary Graduate Program in Energy Planning at the State University of Campinas during my field work. This program is one of three traditional departments in Brazil which are responsible for research and professional training in the electricity sector.[8] Over the course of my research, I attended several roundtables and seminars at Unicamp and other public and private institutions that dealt with the electricity sector. Being a member of this graduate community enhanced my understanding of the Brazilian electricity sector and provided an informal platform where I could exchange ideas with key stakeholders and people who had professional experience in the energy industry.

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[7] For example, Vieira and Dalgaard (2013) argue that the strong pro-hydropower rhetoric is also used strategically by the Brazilian government as political leverage to promote Brazil's position in domestic and international discussions on climate change and energy policy.

[8] These three programs are: the Energy Planning Program (PPE) at the Rio de Janeiro Federal University (UFRJ); the Graduate Program in Energy (PPGE) at the University of São Paulo (USP); and the Graduate Program in Energy Planning (PSE) at the State University of Campinas (Unicamp) where I was based.

3.3. Comparative Case Study Research

Since this project relies on one country for its analysis, it is important to clarify the methodological advantages of using a single country with multiple subnational case studies. A study that takes only national level policies and politics into consideration can miss the important dynamics that occur at both the regional and state level in relation to national level decision-making. A subnational study provides a more accurate examination of how regulations play out on the ground, avoiding what Rokkan (1970) refers to as "whole-nation bias," and it provides better insight into the variation that takes place within states and countries. As Snyder (2001) points out, a subnational study provides an effective way to increase the number of observations when compared to single case studies.

Further, this dissertation's comparative case study design addressed how we can understand the differences in renewable implementation rates in different geographical contexts. For studies of renewable energy development, local and regional differences are frequently attributed to physical advantages, such as high wind speeds and solar irradiation. The "conventional claim" is that natural resource abundance can be readily converted into usable electricity that confers long-lasting forms of regional advantage. While renewable natural resources are confined within a particular physical territory, they are also socially and politically constructed by various networks of actors at different scales (De Laurentis, Pearson, & Eames, 2016). "Physical" potential is not a clear indication that capacity will be realized - that depends on the motivation to invest in an energy technology, as well as its social acceptance. Consequently, investigating the "socio-political" potential in subnational contexts provides a more thorough explanation of geographical differences in implementation rates (Breukers, 2006; Wolsink, 1996).

In line with Flyvberg (2006, p. 221), small-N case studies can be valuable tools in providing practical, context-dependent knowledge, to generalize on the basis of a few cases. They are capable of summarizing and developing general propositions and theories, among other aims. The use of a small number of cases, however, should not to be confused with a "particularizing" analysis (Yin, 2009, p. 15). The identification of similarities and differences in the three state-level case studies allowed me to define dimensions not mentioned or emphasized in the literature that focuses on national-level regulations. These purposive case studies thus provide insights on how policymakers, energy planners, and regional institutions manage the direct and indirect benefits of renewable energy development, which can be generalized to new cases.

By using three states as comparative case studies, the research questions of this study addressed how renewable energy development is conditioned by local contexts. In Brazil, policy design occurs mostly at the federal level, but policy implementation is often conducted by the states. Brazil's federalist system of government creates opportunities for states to influence public policies compared to countries with unitary, centralized systems of governance. The working hypothesis of this study was that differences in implementation rates in wind and solar energy for electricity generation indicate the existence of different state-level policy approaches. São Paulo, Pernambuco, and Rio Grande do Norte were selected to analyze the factors that explained these different approaches, as a type of "two-tail" design (Yin, 2009, p. 59). Rio Grande do Norte and Pernambuco have made concerted efforts to increase their use of wind and solar energy, whereas São Paulo demonstrates a "failed" outcome to implement these two energy sources. The purpose was to overcome selection bias and include a case setting where wind and solar energy have not advanced substantially, despite the physical availability of wind and solar

Table 1

Overview of the State Case Studies

	São Paulo	Pernambuco	Rio Grande do Norte
Overview			
Population	44,749,699	9,410,336	3,474,998
GDP (BRL billion)	1,349 trillion	104	36
Electricity generation in 2015 (%)			
Wind	0.00%	5.87%	70.82%
Solar	0.00%	0.23%	0.04%
Biomass	31.64%	8.85%	1.77%
Hydro	65.09%	17.58%	0.00%
Fossil Fuels	3.27%	67.47%	27.37%

Note. Adapted from IBGE (2016), IBGE (2017), EPE BEN (2016), Aneel (2017).

resources.

Therefore, the subnational component of this research design aimed to gain an elaborate understanding of how local institutions, polices, and practices affect the outcomes in wind and solar implementation. Rio Grande do Norte is a national example of wind energy development, representing approximately 32% of nationally installed capacity in wind energy (see Table 1). The state was a first-mover in the early 2000s in creating policies and regulations to introduce wind energy as an alternative form of centralized generation of electricity. Meanwhile, in terms of solar energy, the state of Pernambuco has been referred to by energy professionals as a pioneer in policy formation: it was the first state to design and hold a solar energy auction, a policy instrument used almost exclusively by national governments to contract energy. Pernambuco also has a considerable amount of installed capacity of wind energy relative to other states. Furthermore, since 2014, national newspapers have reported on state goals to attract wind and solar manufacturing industries (Calixto, 2014). In contrast, São Paulo has no considerable policy developments in wind or solar energy generation, relying on hydroelectric power and sugarcane biomass to produce electricity within the state.

Furthermore, in addition to their observed policy activities, these states were chosen on the basis that they are located in different parts of the country and cover a diverse geographic and socioeconomic distribution. São Paulo is the financial and industrial nucleus of the highly developed Southeastern region of Brazil, while Rio Grande do Norte and Pernambuco form part of the less economically developed Northeastern region. Further, the case selection rationale thus aimed to understand how varying economic circumstances condition regional approaches to renewable energy development. Based on the policy literature, it was further hypothesized that prior investments at the regional level could have a lasting effect on energy priorities. In this regard, São Paulo was also chosen to illustrate the concept of localized path dependency and prior resource commitments, whereby certain technologies become and remain successful over time because of initial advantages (Breukers, 2006). In this regard, the state's prior choices to develop small hydropower and biomass plants have precluded other alternatives such as utilities-scale solar and wind plants.

This sample of three states suffers from at least two limitations. First, the small sample does not allow an investigation of all combinations of factors that contribute to renewable energy development. This limitation is intrinsic to the type of "small N" research. However, as previously mentioned, this approach has an advantage over large statistical studies because it allows the exploration of factors that are difficult to measure systematically and which operate in complex ways in each case. In addition, this study suffers from a selection bias. Even though São Paulo is an unsuccessful example of wind and solar energy, all three states are important economic centers within their respective regions. This study omits examples of states that have attracted wind and solar energy investments, but which have lacked the economic and political resources that have arguably contributed to this study's case findings, such as Piaui and Alagoas. One way to address this gap is for future research to consider less economically developed areas where renewable energy development has occurred.

3.4. Population and Recruitment

Following procedures in grounded theory, a purposeful sampling strategy of potential respondents was employed based on traits theorized to be important to the research topic. This sampling method is similar to strategic non-representative sampling, which aims at variation in the respondents' experiences rather than at representativeness and statistical generalization (Trost, 1986). The population of this study was constructed around energy professionals: broadly speaking, policy-makers, managers, project developers, consultants, and academics that work with some aspect of renewable energy within the electricity sector. The purpose of the interviews was to develop a firsthand understanding of regulatory strategies to promote wind and solar in the energy supply, and to develop an understanding of the institutional contexts that affects energy decision-making at the federal and state levels. Policymakers and regulators have played a decisive role in creating renewable energy policies and regulations, and were consequently an important elite group to interview for this research.

Study participants were further divided conceptually into two target groups. In the first group were representatives from regulatory agencies, government ministries, industry associations, and private utilities companies who possessed relevant professional knowledge and expertise regarding policies that have affected the implementation of wind and solar power at the national level (Kvale, 2009). In a second group, participants were interviewed based on their experience with supporting or devising policies to develop renewable energy at the state or regional level. These included representatives from state-level energy, science, and technology agencies and institutes, regional economic development agencies, and environmental secretariats. The focus of interview guidelines for state-level actors was on non-federal policies and programs enacted by state governments. However, at the end of each interview, I also asked a general question about the role of the energy regulator, Aneel, in energy policymaking if the interviewee had not already addressed the topic. This allowed me to gather more perspectives on regulators and how regulations affect policy. Table 1 outlines the different types of public and private organizations that were interviewed for this research.

Table 2

Organizations that Participated in this Research

Organization of interviewee	Number interviewed
Central Government Level	
Brazilian Electricity Regulatory Agency (ANEEL)	5
Ministry of Mines and Energy (MME)	1
Energy Research Enterprise (EPE)	1
Brazilian Development Bank (BNDES)	2
Regional Level	
State Energy Secretariat	15
State Trade and Industry Secretariat	6
Regional development banks	3
Private sector and non-profit	
Energy investment companies	2
Energy consultancies	2
Non-profit organizations (NGOs)	2
Universities and educational institutions	3
Total	43

Professional interview introductions were made via personalized emails. This allowed me to establish a rapport and make my methods and motives transparent prior to the interview (Rubin & Rubin, 2011). For most policy-makers and energy professionals, it was explained that the subject's contact information was obtained from their organization's website, and that the interview would be confidential and voluntary (see Appendix C for a sample recruitment email). If a participant was referred by another interviewee, it was explained that their contact information was provided by a colleague or acquaintance who knows the subject.

Verbal consent was obtained in this study. Before formally beginning the interview, I verbally expressed who I was (name, university and graduate program, dissertation adviser) and the reasons for my study. I stated that, in agreeing to the interview, they were not obligated to answer any questions that would make them feel uncomfortable, and that they had the right to stop the interview at any time. No interviewee refused to respond to a question or decided that she needed to stop and withdraw from the interview.

3.5. Data Collection and Analysis

Interviews were conducted with 43 participants from January 2016 to November 2017 in Pernambuco, Rio Grande do Norte, São Paulo, Rio de Janeiro, Rio Grando do Sul, and Brasilia, the national capital. Interviews ranged in length from 35 minutes to one hour and 40 minutes. Traveling to these different regions in Brazil and visiting areas with high levels of wind and solar penetration further provided me with a sense of the pattern of development behind these technologies.

The interview guidelines were structured around three main subject areas: (1) an overview of the interviewee's organization, including general activities and objectives in the energy field; (2) the point of view of the interviewee regarding certain public policies and regulatory changes; and (3) the interviewee and/or her organization's activities in terms of reacting to, blocking, or supporting wind and solar energy projects. (See Appendix C for sample interview protocols.) They were recorded digitally. During the introduction, participants were informed of the interview length (up to 90 minutes, unless an alternative length was established by the interviewee), of their right to confidentiality, and of my request to record the interview. All interviews were conducted in Portuguese, with the exception of two interviewees who had studied and/or worked outside of Brazil and preferred that the interview be conducted in English.

The content of the interviews was adjusted to the specific expertise and characteristics of the interviewee. I reflexively developed individualized interview guides. For the preparation of each interview, I reviewed organizational homepages and newspaper articles. I began with a set of underlying questions, wrote how I expected the specific professional to respond, analyzed what assumptions I had made about that professional, and noted my preconceptions about the interview. Throughout the interview, I actively engaged with the respondent to discern her meaning, giving her a chance to rephrase and clarify. Interviews were generally characterized as "direct questions": while the interviews at times took on a conversational tone, the subject always centered on their personal and institutional knowledge regarding the research topic. I also took handwritten notes during the interview to register points raised by the interviewee that I considered important and intended to revisit during transcription. Pre-interview notes, handwritten notes, and interview transcripts were reviewed together during data analysis.

All informants were interviewed in their private offices or closed conference rooms. One energy consultant was interviewed in a busy café near his office, at his suggestion, and another policy-maker was interviewed over the phone. Such spaces and mediums of communication were agreed upon as secure by both the researcher and the participant, where it was reasonably expected that no observations or outside recordings could take place. In the case of six (6) state and national-level policy-makers, interviews were conducted in the presence of one or more colleagues. This was in accordance with ethics policies followed by some Brazilian government agencies, in which a civil servant must be accompanied by at least one colleague during a private interview. Before starting my field work, I was unaware of these ethics procedures during interview situations in Brazil. I thus had to adjust my interview demeanor to be prepared for situations where I would be in the presence of more than one person without being advised beforehand. I also described my own thoughts on how their colleagues might have influenced their responses in my field notes.

The data analysis began as soon as data were collected. This analysis was then used to direct the next set of interviews and other observations, enabling the research process to systematically capture all potentially relevant aspects of the topic as soon as they were perceived (Corbin & Strauss, 1990, p.6). I transcribed interviews while noting potential codes and questions (e.g., attitudes towards certain government regulations and administrative obstacles to supporting wind and solar energy) to identify recurring sub-themes and themes to investigate differences and similarities in responses. Requiring the concept or code's relevance through continued scrutiny and new data is also one way to guard against researcher bias and the meaning that the researcher brings to the research (Corbin & Strauss, 1990, p.7). The number of interviews was informed by a saturation point. I stopped interviewing when very little new information was being produced which sparked new insights.

In the individual case studies of wind and solar energy, I applied a method called process analysis (or "history event analysis") to create deeper insight into the creation and evolution of innovation systems for the respective technologies (Abbot, 1995). For this research project, process analysis was used to analyze the development, diffusion, and implementation of wind and solar in Brazil. The aim was to provide insights into policy processes by focusing on the resulting patterns of activities carried out by actors involved in the regulatory process.

3.6. Reliability and Quality

The purpose of this research was to explain a phenomenon: how wind and solar energy have gained prominence in a system that has been historically dominated by an incumbent technology, in this case large-scale hydroelectric power. This study's findings are not meant to be generalizable to a specific population per se, but to broader theoretical concepts about technological change and renewable energy development. This study makes explicit the broader structural conditions which hinder or support wind and solar, while drawing out the energy regulator as a key actor in enabling the successful inclusion of these two energy sources. The specific actions and strategies taken by the energy regulator were then generalized to longstanding theories on how regulatory agencies should administer utilities policy. In a similar way, the state case studies offer a comparative perspective on the broader strategies that regions employ to fulfill local economic development and environmental goals. While these findings are meant to be generalizable to concepts and debates established in the literature, particularities exist within the data and may therefore not be applicable to new situations.

I used two main strategies to strengthen the accuracy and validity of the study's findings. I first triangulated findings by including several individuals from different organizations and businesses as sources of data (Mathison, 1998), and by attending and systematically taking notes at public conferences and events on ongoing developments in the electricity sector. I also employed "peer debriefing" to enhance the accuracy of the account (Creswell, 2014, p. 202). I sought out colleagues in my host department at the University of Campinas to respond to my questions as an ongoing way to assess validity throughout the study. Many of my colleagues had worked for electricity distribution companies in either a professional or Research & Development capacity in the past. During debriefings, I did not identify the names or positions of particular individuals who I had interviewed but rather asked for feedback on general issues raised during the interviews. I used these techniques to examine my developing explanations and thinking about the research process. This allowed me to construct more plausible explanations that accounted for the institutional context behind renewable energy development.

Lastly, the findings resulting from this study are also reproducible in the limited sense that they are verifiable (Corbin & Strauss, 1990, p.15). No quasi-experimental research design which deals with social phenomena is reproducible in the sense that new conditions can be found which exactly match those of the original study. The broadness of the propositions, however, ensures that they can be tested in other conditions.

3.7. Changes to the Original Study Design

In the original design, it was stated that the study would consider two regulatory policies: the expansion of universal access to electricity, and the promotion of renewable energy in electricity generation. By taking this study to the sub-sectoral level, the intent was to compare how regulators achieve different policy-oriented goals in the energy sector. To conduct this research, interviewees would have included low-income electricity consumers to understand how they use and afford electricity. As a result of this original study design, three informants were interviewed form July-August 2014: one community leader of an informal community, also known as a “favela,” one university professor, and one manager for an electricity distribution company. All of the interviews took place in São Paulo. Based on the researcher’s interests, the study's aim centered on understanding how changes in the electricity sector have influenced the use of renewable energy sources. These interviews were not directly used in the final analysis.

In addition, the state of Rio Grande do Sul was originally considered as a potential case instead of Pernambuco. Rio Grande do Sul was thought to be a strong candidate for a case study because it is the second largest producer of wind energy in Brazil. It was also thought that its location in Southern Brazil would have provided insights into the significance of geographic and economic context for developing energy policies.

By December 2016, however, I decided that it was in the best interest of this study to substitute Rio Grande do Sul for Pernambuco for two reasons. First, I conducted preliminary interviews with government officials in Rio Grande do Sul; one interviewee was with an economist at a regional development bank, and the other interview was conducted with a group of representatives from the state secretary of energy. In short, the interview at the state energy secretariat did not go well. The manager in charge of renewable energy programs was uncooperative during the interview. I thus judged that it would be very difficult to obtain additional information or conduct follow-up interviews about these programs in Rio Grande do Sul. I did decide to use these interviews in the final analysis because they pointed to general challenges that state governments face in managing renewable energy investments. Rio Grande do Sul was also excluded because of its low implementation of solar energy. Pernambuco was brought in to provide a stronger perspective of state-level solar policies.

3.8. Reporting the Findings

The final written product is a narrative text. The results are presented in a descriptive, narrative style shaped by policy and theoretical debates. The final project is a construction of the participants' reports on events and changes in the energy sector in relation to codes and themes that emerged during the data analysis. The use of short and long embedded passages were used to convey descriptions and themes developed from the data.

Chapter 4

The Brazilian Electricity Sector

"Brazil will never stop being a hydro-based country."

- Representative from the Ministry of Mines and Energy (2017) [9]

This chapter places the origins of the Brazilian power system into historical context. It begins by discussing how the industry structure and regulatory framework co-evolved with the centralized planning of the country's hydrological resources. The claim of this chapter is that in spite of market-oriented reforms and restructuring in the 1990s, which could have introduced new sources of power generation, the hydroelectric system continued to be closely intertwined with the planning and regulatory system. As a result, the rules and institutional supports that historically favored hydropower have locked-out the diffusion of other technologies, even when they have demonstrated improvements in the established system (Unruh, 2000). A national energy crisis in 2001 marked the beginning of broader support for non-hydro renewable energy technologies. This chapter concludes by suggesting that regulatory agencies, a central feature of electricity reforms, can create opportunities for new renewable technologies.

[9] Translated quotation that appears above: O Brasil nunca deixará de ser um país hídrico.

4.1. Introduction

Brazil is physically vast and the fifth largest country in the world, covering a a total area of 3,287,956 square miles (8,515,767.049 km2) (World Bank, 2017). Its approximately 208 million inhabitants are concentrated primarily in large cities along the Atlantic coastline (IBGE, 2017b). The Brazilian federal system shares power between the twenty-six states and the central government. At the federal level, power is divided between the Executive, led by the President of the Republic who names political appointees to key administrative positions, and the Congress. The administrative capital is Brasilia, while São Paulo and Rio de Janeiro drive growth in the service and industrial sectors of the economy.

The country's large hydroelectric capacity stems from three major river systems, including the Amazon basin (Vieira & Dalgaard, 2013, p. 615). Since the 1980s, hydropower has provided more than 80% of Brazil's electricity. Large-scale generation facilities tend to be located in remote regions in the North and South of the country (hydroelectric projects), or in the less populated and less developed Northeast (wind farms). A consequence of this spatial dispersion is that extensive networks of long-distance transmission lines have been developed to transport energy to demand centers (see Figure 2).

Table 1 shows the growth of energy resources in Brazil in 2012 and 2017. Hydroelectric plants represented approximately 65% of installed capacity in 2017. While hydropower occupies the majority of the total electricity supply, fossil fuel-based thermoelectric plants were first constructed to compensate for the lack of hydroelectricity during periods of low rainfall, and represent the country's second largest energy source. In terms of non-hydro renewable energy, wind power is the fastest growing source where Brazil is ranked 9th globally. Biomass from sugarcane, forest residues, and waste from the pulp and paper industry generate approximately

9% of electricity. Policymakers have only recently admitted utilities-scale solar into supply planning and consequently it represents a small percentage of total supply.

Table 3

Installed power capacity in Brazil

	2012		2017		
	Installed Capacity (GW)	%	Installed Capacity (GW)	%	Δ 2017/2012
Hydro[b]	84.29	69.67	98.03	65.64	16.30
Nuclear	2.01	1.66	1.99	1.33	-0.10
Biomass	9.92	7.64	13.26	8.88	33.47
Wind	1.89	1.56	10.94	7.33	478.84
Solar	0.02	0.017	0.17	0.11	750
Fossil Fuels	21.44	17.72	24.96	16.71	16.42
Total	120.98	100	149.35	100	-

Note. Adapted from Aneel's Generation Information Bank (BIG) (Accessed September 1, 2017)
[a] Distributed generation is not included.
[b] This figure includes large hydro, small hydro, and central hydroelectric generators.

4.2. From Private Sector Foundations to Growing Nationalization

The earliest power utilities in Brazil were private companies that owned and operated exclusive concessions in major cities and for large industries. While Portuguese colonialization began in the Northeast in the beginning of the 16th century, after World War II, the Southeast region ascended as the pole for national industrialization. Electrification was centered on growing industrial centers in São Paulo, Rio de Janeiro, parts of Minas Gerais, and the southern part of Bahia (SP SEM, Interview, Dec. 8 2016). Beginning in 1897, Light, a Canadian utilities group, built much of the early electricity infrastructure in Rio de Janeiro and São Paulo. The U.S. firm AMFORP also obtained the rights to build and manage electricity in several other large towns. Without an established federal process for awarding public concessions for power services, each municipality created its own rules on which private utilities companies based their operations (de Oliveira, 2007).

The Brazilian electricity sector was largely decentralized and uncoordinated until the 1929 New York Stock Exchange crash. Coffee exports, the single tradable Brazilian product in those years, dropped dramatically, pushing the domestic economy into a recession (Furtado, 1964). To stabilize the economy and guide national development, the federal government began to eclipse some of the powers of the twenty-six states. Since electricity is a key input for industrialization and economic growth, the decision to grow the industrial base with import-substitution policies involved expanding the electric power system. Consequently, the role of foreign companies in the energy sector became a political issue. Liberals had argued that foreign investors would bring technology and capital, both scarce in the country. On the other hand, nationalists viewed the energy supply as a strategic factor of production and could not be left to foreign control (de Oliveira, 2007). These initial political and macroeconomic debates foreshadowed the increasing intervention of the Brazilian state in electricity supply and distribution. In the end, the nationalists came out ahead. In 1934, the federal government adopted the Water Code. This cornerstone legislation granted the Brazilian state the property rights for rivers and the authority to regulate power services, laying the foundations for the state-led development of hydroelectric power (Abers & Keck, 2013).

4.3. The Expansion of Hydroelectric Power Generation

From the 1940s and through the 1960s, the federal government sought greater control over electric utilities. Hydroelectric potential was being gradually exhausted in the Southeast, and new plants had to be constructed farther away from large cities and urban areas to meet the rising demand for electricity (SP SEM, Interview, Dec. 8 2016). Starting in 1945, the Brazilian government created Eletrosul, Furnas, Chesf, and Eletronorte. These federal power companies built and operated large hydroelectric plants in the Southern, Southeastern/Midwestern, Northeastern, and Northern regions of the country, respectively. The government eventually put these entities under the control of a singular holding company, Eletrobras, making the central government the primary owner and manager of the transmission system and also of much of the hydroelectricity generated in the country (Bajay, 2006, p.866). State governments formed distribution and retail supply companies, and some were also involved in generating and distributing electricity.[10] To develop the incipient oil market, Petrobras was created as a legal monopoly in 1954. Like many countries at the time, monopoly under government control was seen as the best means to extend electrification.

Throughout the military period (1964-1985), planning and decision-making within the Brazilian electricity sector became more centralized.[11] The government encouraged the development of the country's natural resources and river basins to stimulate economic growth. As the economy grew, so did the demand for electricity (Vieira & Dalgaard, 2013, p. 611). The National Department of Water and Electric Energy (DNAEE) was founded in 1965 with the purpose of managing freshwater resources. From the 1970s onward, hydropower grew to represent over 80 percent of Brazil's electricity production. Eletrobras used its control over state funds for building power plants and pursued vast projects, such as the Itaipu hydroelectric dam on Brazil's shared border with Paraguay (de Oliveira, 2007, p. 31). There was no independent regulator or systems operator separate from the political bureaucracy, and the Ministry of Mines and Energy and DNAEE were in charge of policymaking and de facto regulation.

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[10] These energy companies owned by state governments include Cesp in the State of São Paulo, Cemig in the State of Minas Gerais, Copel in the State of Parana and CEEE in the State of Rio Grande do Sul,

[11] On April 1, 1964, the Brazilian military overthrew then president João Goulart. See Skidmore (1990).

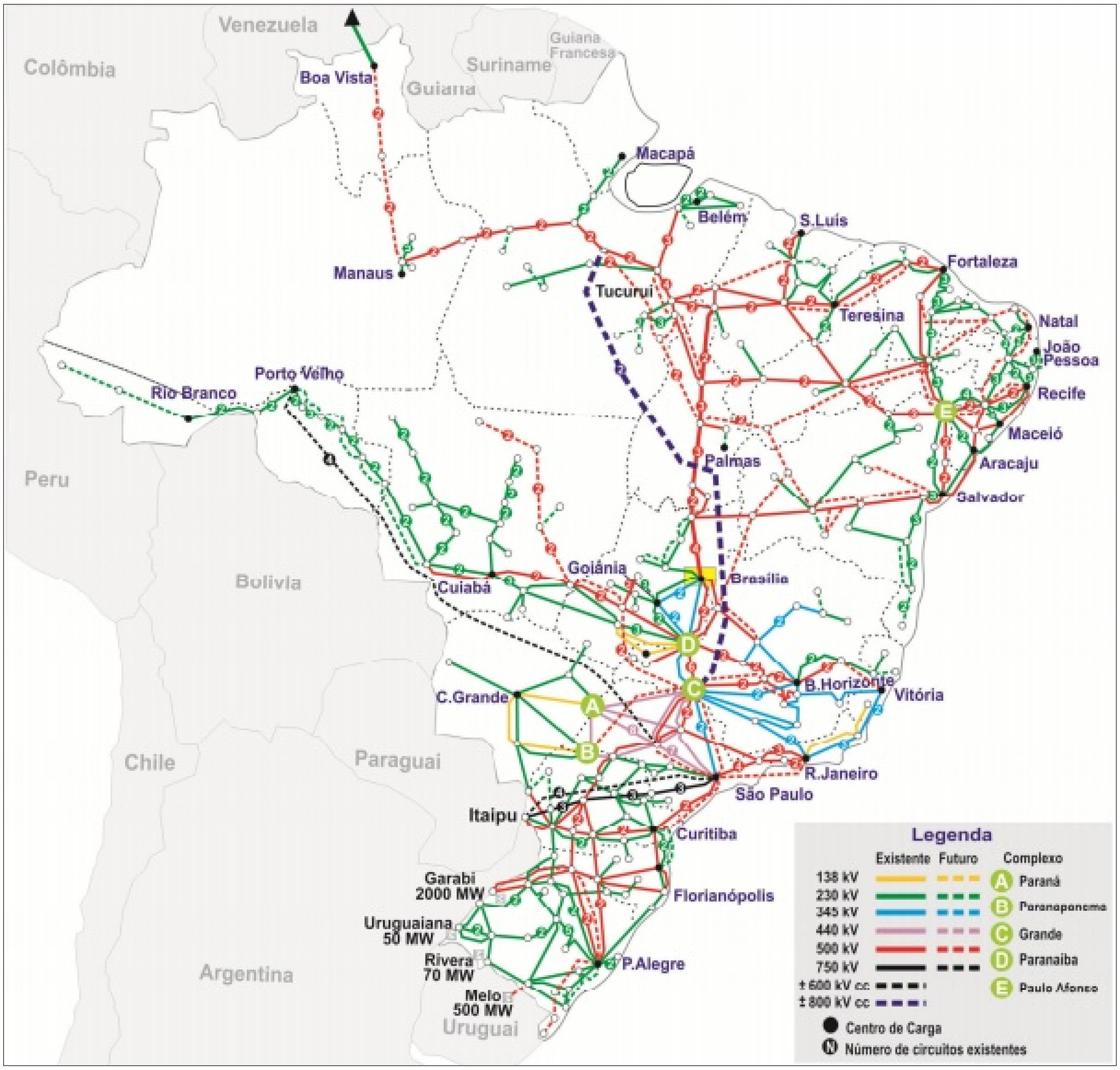
The OPEC oil crisis from 1973-1979 represented a critical juncture in Brazilian energy planning. The twin oil price shocks set off an upheaval in the global economy which hit many petroleum-importing countries. At the time, Brazil was importing 80% of its petroleum. The rise in the price for oil disrupted supplies and threatened the country's economic development plans. Consequently, energy sovereignty rose higher on the policy agenda, and the military government saw energy independence as a matter of national concern. Since the technological and institutional framework was already well-developed around hydropower, the ability to build out the supply capacity with hydroelectric plants, rather than with imported crude oil, reinforced the notion among policymakers that Brazil was a "hydropower country" (de Oliveira, 2007, p.37).[12] Another salient government initiative was the launching of the National Alcohol Program (Proálcool) to replace gasoline consumed in the transport sector with sugarcane ethanol. Like hydropower, ethanol was not initially conceived as a source of renewable energy, but as a means of reducing Brazil's dependency on imported petroleum (Vieira & Dalgaard, 2013, p. 618).

The National Interconnected System (SIN) was further designed with the objective of maximizing the number of hydroelectric plants in electricity production. Managed by The Electric System National Operator (ONS), the SIN is an extensive transmission infrastructure which serves all Brazilian states and transports over 98% of the electricity produced and consumed in the four regional subsystems: the South, Southeast/Center-West, Northeast, and North grids. Given their industrial and economic importance, the South and Southeast became the first regions connected by the SIN in the mid-1970s. Under its original conception, fossil fuel-based thermoelectric plants were used in cases where hydroelectric plants were unable to supply sufficient energy to the electricity grid. The SIN was thus intended to unify the country's hydroelectric generation and transmit it to demand centers (see Figure 2 below).

[12]Nuclear energy was also debated as an alternative technology to supplement hydropower.

Figure 2

Diagram of the Brazilian National Transmission System (SIN)



Note. ONS (2016).

4.4. Privatization and Regulation in the Brazilian Power Sector

The public ownership framework of federally- and state-owned companies responsible for electricity generation and supply in Brazil lasted until the mid-1980s. The low price for electricity and a growing energy supply had largely achieved what they were intended to do – fuel Brazil's rapid economic development. The Brazilian economy grew at a rate of around 10% per annum between 1968 and 1973. However, the "miracle years" of state-led development eventually triggered the unraveling of the electricity sector model. The military government had tried to ensure economic growth while downplaying the financial viability of public sector companies. The artificially low tariffs for electricity were often vain efforts to control high inflation rates and achieve other political and economic objectives. The practice of fixing electricity tariffs below costs had led state-owned utilities companies to accumulate high amounts of debt, which were then exacerbated by the shocks of the oil crises and ensuing economic instability (Tanka, 2008, p. 154-156). Politically appointed managers of state-owned companies had also done little to protect environmental quality as they built ever-larger hydroelectric projects (de Oliveira, 2007, p.45).

By the end of the 1980s, the decline of an institutional model based on strong public sector involvement led to a search for alternatives. In 1995, a political ideology of privatization spurred the momentum to reform the power sector. Based on principles of market deregulation pioneered by Chile and Great Britain, then-President Fernando Henrique Cardoso's administration initiated a restructuring process that aimed to stimulate competition and attract private investors to generate and supply electricity. The Brazilian government would drastically reduce its role by privatizing the distribution sector and some hydroelectric generators.[13] As a

[13] Victor and Heller (2007) note that reform strategies have differed in whether to lead reforms with the generation or distribution side of the power sector.

result of broad-based privatization and restructuring, 70 percent of distribution assets and 30 percent of generation capacity were initially privatized. Distribution companies were privatized as 30-year concessions. Generation companies were auctioned as 35-year concessions and were required to sell their power in competitive wholesale markets. The large generation and transmission companies — Furnas, Chesf, Eletronorte, Cemig and Copel — continued to be state-owned. This partial privatization of utilities was caused by strong political opposition to privatization both within and outside of government (Bajay, 2006, p.867).

The National Privatization Program in the 1990s introduced independent regulatory agencies in Brazil as modern forms of market regulation.[14] Previously, the Ministry of Mines of Energy, DNAEE, and Eletrobras had been traditionally responsible for most aspects of energy planning. One of the first steps of Brazil's reform program was the establishment of Aneel in 1996, a quasi-independent regulatory body charged with overseeing the electricity sector. Reformers conceived Aneel as being at the center of policy implementation, although the agency faced considerable review of its functions and resources in the electricity sector (Lock, 2005). In turn, the Ministry of Mines and Energy was to reduce its role in the construction of hydroelectric projects, but remain in charge of coordinating long-term supply planning.

The prevailing institutional context in Brazil influenced the design and vision for the new energy regulator, Aneel. At the federal level, the reform of the electricity sector centered on how to renovate existing institutions to meet the challenges of privatization. Over the 1980s, DNAEE, the federal agency responsible for water, hydroelectric dams, and monitoring the power sector, became increasingly seen as bureaucratically costly and underperforming (Nunes, 2007, p.63). DNAEE encompassed a staff of 600-700 civil servants and, while it counted on a capable

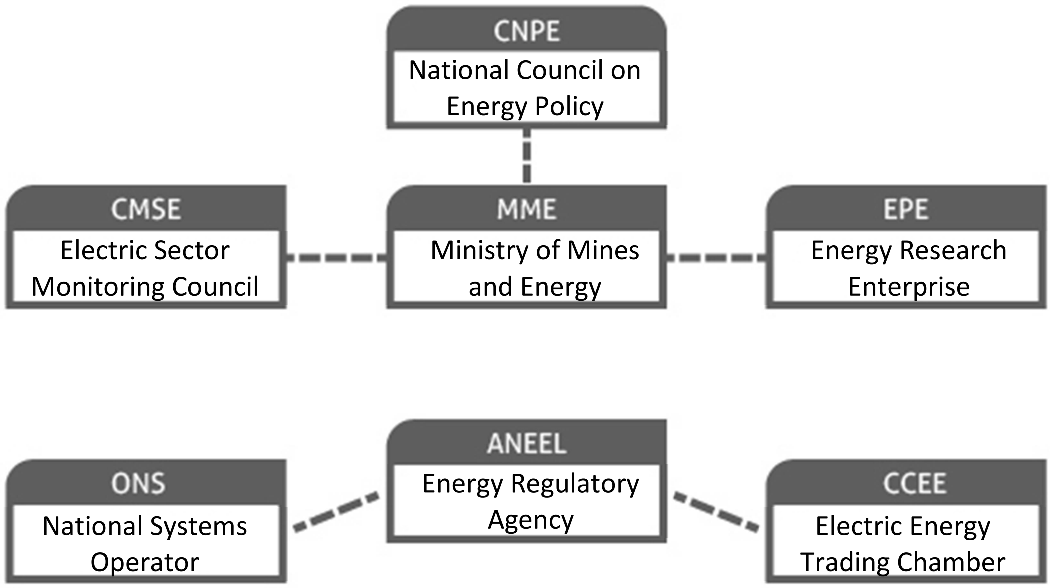
[14] In a parallel fashion, the National Telecommunications Agency (ANATEL) and the Petroleum, Natural Gas and Biofuels National Agency (ANP) were created to regulate their respective infrastructure sectors. It should be noted that the ANP physically adjoins Aneel's offices in Brasilia.

technical team, most employees had not been subjected to technical selection criteria during recruitment. Moreover, having been subordinated as an administrative arm of the Ministry of Mines and Energy, it lacked independence. By 1995, an organizational alternative which could safeguard investor confidence and provide transparent decision-making was already being discussed within the department (Nunes, et al., 2007, pg. 63; Ribeiro et al., 2006, p.12). Aneel would be vested with the fundamental role to depoliticize the electricity sector and set the stage for market-oriented energy policies. The image of the new energy regulator was framed in contradistinction to DNAEE: it would be independent from the interventionist tendencies of the administrative bureaucracy (de Oliveira, 2007, p. 32).

In addition to founding Aneel, a set of central institutions were created to direct the future course of Brazil's power sector (see Figure 3). Among these were the National System Operator (ONS) in 1998, the central dispatcher which balances supply and demand for electricity within the interconnected transmission system. The CCEE (Electric Energy Trading Chamber) replaced the MAE (Wholesale Market of Electric Energy) and coordinates the wholesale market and regulated contracting environment. In 2004, President Lula's government created the Energy Research Enterprise (EPE). Linked to the Ministry of Mines and Energy, the EPE is a semi-autonomous planning and research agency which carries out long-term expansion planning for the electricity sector (Hochstetler & Tranjan, 2016).

Figure 3

Diagram of the Brazilian Electricity Sector



Note. Authors' adaptation of the CCEE's institutional chart (CCEE, 2018).

As part of the new planning model for energy expansion and regulation, two trading environments were created in the wholesale market: the regulated contracting environment (ACR) and the free contracting environment (ACL). In the ACR, distribution companies purchase energy at public auctions by submitting demand projections with five-year horizons to the EPE. Based on these projections, the EPE sets the total amount of electricity to be contracted in the auctions. The EPE gathers baseline data and guides firms through the bidding and licensing processes (Hochstetler & Tranjan, 2016). In the ACL, large consumers are free to choose their suppliers outside the centralized auctions. Energy sales are negotiated through bilateral contracts with generators and traders, and are subject to federal oversight from the CCEE. The public-private ownership system allows public and private sector companies to compete freely in the market for supplying electricity and provides the opportunity to compare total price efficiency in the two sectors. If the private sector bids too high for a supply contract, the public sector will undercut them, and vice-versa (Tankha, 2008, p. 160).

As of 2017, private companies that are non-utilities own 60 percent of generation in Brazil. Much of the non-utility generation is under long-term contract to utilities. Approximately 40 percent of transmission and 71 percent of distribution is privatized (Portinari, 2017)).

4.5. Public Support for Non-hydro Renewable Energy Alternatives

The electricity reforms that Brazil adopted in the late 1990s marked an opportunity to diversify the energy supply away from hydro. In theory, the market-oriented approach was technology-neutral: any energy source could be considered a fair candidate. At the same time, several arguments were being made for cleaner and more diversified electricity sectors that drew on recent advances in renewable energy technologies. Following the 1992 United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, international and domestic stakeholders advocated for more environmentally friendly sources such as wind, solar, and biomass. In addition, environmental actors in Brazil had gradually brought to light the social impacts of large hydroelectric projects. The environmental movement was also highly critical of electricity utilities' quest for expansion and their disregard for environmental concerns. With the return to civilian government and democratization, the voices of opponents to large hydro began to matter in national policy debates over energy (Vieira & Dalgaard, 2013, p. 615). The fact that Brazil had already tapped 75 percent of its hydroelectric potential was cited as an additional reason to branch into alternative energy.

While sustainability concerns gained importance in energy policies, hydropower was given continued priority in Brazil's energy expansion plans. The mounting pressures to diversify the energy supply did not provide a sufficient counterbalance to the pre-existing hydropower framework. The hydroelectric system's organizational principles and characteristics led to a situation of "lock-in" in which centralized hydropower has remained the dominant from of energy production, while creating a strong resistance against introducing alternative energy technologies (Geels & Kemp, 2007). For a number of reasons, "hydro lock-in" has created constraints for achieving emerging policy goals such as energy security.

First is the fact that the price of hydro-based electricity is the lowest among all sources of energy. The central dispatcher, the ONS, selects which generators can supply electricity to the grid based on their declared variable costs. In terms of the technological and financial characteristics of hydropower, enormous capital investments are required during initial dam construction, but the operating costs are typically very low in comparison to other major electricity sources. The functional life of a hydroelectric plant is longer than its amortization period, the length of time that it takes to pay back a loan for the initial capital and construction costs. Since the majority of hydroelectric plants had their capital costs amortized before the liberalization of the electricity market, they do not have their past financial and environmental costs figured into their variable costs. These old hydropower plants only have to recoup operational costs and, therefore, have more flexibility in setting prices in the free market, where consumers negotiate power supplies directly with generators and traders. These power plants thus compete asymmetrically, making it difficult for new technologies to enter the generation market (Cavaleiro & Silva, 2005; da Silva et al., 2013, p.691).[15] Their significant share of the electricity supply can be likened to a "first-mover advantage": as preliminary entrants, these

[15] As described later on, the auction system was designed to differentiate between "old" and "new" power facilities. One of the reasons was to take into consideration the characteristics of old hydroelectric plants which have already been installed and "paid for," and which could consequently out-compete new investments in energy.

early hydroelectric plants gained a significant competitive advantage and continue to control a large share of generation in the electricity sector.

In addition to hydro's low prices to supply electricity, the incipient regulatory structure inherited institutional endowments from the previous system. In practice, the underlying rules and market structures that determine which power plants are selected to supply electricity are far from being technologically neutral. The centralized dispatch rules give priority to hydropower when prioritizing which power plants the systems operator will deploy to service the electricity grid. Hydroelectric plants are considered must-run baseload plants that are always "turned on" to maintain the electricity grid's voltage, frequency, and reliability.[16] These plants are allowed to supply electricity nearly continuously and will be dispatched ahead of any other primary source except nuclear, which is also classified as inflexible. The implication is that the central supply dispatcher gives lower priority to other sources, such as wind and solar.

Lastly, the political culture to promote and sustain hydropower was integrated into the new regulatory order. The initial winners that emerged from institutional reforms were the well-organized interests of hydroelectric operators. The political slang term, *eletrocratas*, is used colloquially to refer to career bureaucrats who were trained in the engineering and political culture cultivated during the golden age of large hydropower and hydro-based megaprojects. These professional elites have been largely brought into the new regulatory regime (de Oliveira, 2007, p.73; Unicamp, Interview, June 15, 2016).[17] For them, continuing to build up the hydroelectric sector was part of common practice and integral to their belief system. For

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[16] Electric power generators connected to the electricity transmission and distribution grid function not individually but as part of a "team" of generators, turning synchronically with the frequency of the grid. Some power stations are "frequency regulators." They maintain the grid's overall frequency so that other power stations can continue to generate power.

[17] This research looks at elitism indirectly by focusing on policies and regulations that energy elites have defended within the electricity system. For a more focused elitist perspective that explains how individuals and groups amass power and influence within large, energy-based technological systems, see Hirsh (1999).

example, during restructuring, Aneel passed a resolution to incentivize small hydro power plants, giving special operational discounts to plants with installed capacities of fewer than 30 megawatts (Aneel, 1998). Other types of renewable energy facilities, such as wind farms, have had to adapt to standards that were intended to guarantee the expansion of hydropower. These informal institutions, based on vested interests and ideological commitments regarding what are politically and culturally appropriate forms of electricity generation, have also contributed to system inertia.

The necessary political will to make more systemic changes to the electrical supply system was precipitated by an energy crisis in 2001. Until 2001, the country relied on hydroelectric power for 88-percent of its generating capacity, and there were no significant incentives for non-hydro renewable energy technologies. Beginning in July of that year, a severe drought had reduced the water levels of hydroelectric reservoirs and resulted in major disruptions and power rationing. The Southeast and Northeast reservoirs were at only one third of their full capacities, an amount that was insufficient to meet the demand until the start of the next rainy season. The government first lodged the origins of the crisis in climatic factors and unpredictable rainfall. An important factor, however, was that generation investments had been added at a slower rate than consumption between 1990 and 2000 (Tolmasquim, 2000). The immediate reaction of the government was a demand-side solution: energy supplies were rationed for eight months and energy efficiency measures were gradually phased in to reduce the demand for electricity. In response to the prospect of another energy crisis, the Brazilian Government accelerated the construction of thermoelectric power reserves to stabilize supply levels.[18]

[18] Since the 1980s, the Brazilian government had positioned fossil fuels, primarily natural gas, as a way to complement the hydropower system and boost supply security. The government created the Priority Thermo-electricity Program (PPT) to stimulate investments in thermoelectric plants, but plants were not built fast enough to keep up with expansions plans under a more liberalized framework. In this view, attempts to diversify the supply

The crisis had a lasting effect on the broader policy environment that strongly relied on the performance and stability of hydrological resources. The reoccurring power supply shortages provided an external pressure to expand and diversify the electricity matrix. Furthermore, by early the 2000s, the wind power booms in California, Denmark, and Germany had dispelled the notion that wind was an unviable power option (Heymann, 1999). The anti-nuclear movement had also influenced the public's general opposition to nuclear energy. These changed technical and cultural conditions presented electric power reformers with new options for how to craft a new supply model for the power sector. While hydropower formed the backbone of the energy system, the solution to future energy problems no longer relied exclusively on hydroelectric power.

In addition to energy conservation measures, policy-makers responded to the energy crisis by creating a number of government supports to foster markets for renewable energy sources. In 2002, the Program of Incentives for Alternative Energy in Electricity (Proinfa) introduced feed-in tariffs for wind, biomass, and small hydro but did not include solar. In 2004, the government established energy auctions as the main policy mechanism to attract new generation capacity. While many auctions have been restricted to hydro, technology-specific auctions have been conducted for wind, solar, and biomass (Hochstetler & Kostka, 2015; Batlle, et al., 2010). After a preliminary round to ensure competition, a second "pay-as-bid" round awards the lowest bids with a power purchase agreement (PPA) (Elizondo et al., 2014). The

with natural gas proved just how difficult it was to integrate other technologies into Brazil's hydro-based electricity system.

Brazilian Development Bank (BNDES) provides credit for approved energy projects at subsidized rates.[19]

Another way to encourage renewable sources of energy has been the establishment and subsequent revision of a national net-metering framework. In 2012, with the global cost reductions for solar technologies and equipment, the Brazilian Electricity Regulatory Agency (Aneel) created net-metering regulations to reduce regulatory barriers for small-scale distributed generation systems. Although a variety of renewable energy sources are eligible under net-metering regulations (Jannuzzi & Melo, 2013; Mattar et al., 2015), they were essentially designed to stimulate solar power generation. At 194 MW, solar photovoltaic (PV) systems represent 72.5% of installed capacity in distributed generation connections (Aneel, 2018a).

In addition to explicit government supports, the new electricity market structure provided the basis to expand the power system with non-hydro renewables. After the victory of the Workers' Party in 2002, power reformers introduced a new class of participants in the electric utilities sector: the Independent Power Producer (IPP). An IPP, or non-utility generator (NUG), is an entity which owns facilities to generate electric power for sale to utilities and electricity consumers. It is not a public utility involved in electricity distribution. Previously, federally and state-owned power companies were primarily interested in building big power plants that were infeasible for most renewable technologies at the time, except for hydroelectricity. There were also a few vertically integrated power companies owned by the state governments in Brazil's industrialized southeast and southern regions (Tankha, 2008), which produced and sold electricity to end consumers almost exclusively from their hydroelectric plants. Following sectoral restructuring, the opportunity for independent power producers to enter the generation

[19] The BNDES no longer provides subsidized loans for fossil fuel-based thermoelectric plants following Brazil's participation in the Paris Climate Agreement.

market interested many medium-size companies that considered producing energy from sources other than hydro. The prospect of government incentives to encourage the development of biomass and wind has also been an attractive incentive for new investors.

Another drought in 2012 provided a renewed stimulus for non-hydro renewable energy sources. From mid-2012 to late 2015, the average water levels in river basins had been below historical values. In response, the federal government deployed electricity from fossil fuel-based thermoelectric plants, powered primarily by coal and natural gas, to guarantee the country's electricity supply and allow a recovery in reservoir levels. In the medium-run, this caused the price of electricity to rise, leading to an unprecedented increase in energy tariffs in 2015. To mitigate the financial impacts on distribution companies' revenues, the federal government decided to use the Energy Development Fund (CDE), a public benefit fund created to promote renewable energy and energy efficiency, to compensate distributors for the additional costs incurred. High electricity prices are politically unpopular, and the government used its control over the energy sector to keep prices low and avoid the pass-through of these costs to final consumers (CPFL Energia, 2012). In compensating for the system's inherent hydrological risks, the over-use of thermoelectric plants causes high electricity prices and emissions.

Despite a growing consensus to develop the country's non-hydro renewable resources, the government has been intent on expanding hydroelectric power. Under the Worker's Party government, the EPE released an expansion plan in 2007, which it later revised in 2010. It anticipated an annual increase in energy production, amounting to 40,000 MW by 2020, mostly from building new hydroelectric power plants in Northern river basins. Considering the sensitivity of the Amazon region, dam construction continues to exemplify the clash between development and conservation policies (Vieira & Dalgaard, 2013). Moreover, the main rivers targeted for hydroelectric expansion overlap with territories of several traditional communities. The reliance on large-scale hydroelectric power plants in the Amazon has triggered major debates about the actual sustainability of hydropower, the unequal distribution of benefits, and the socio-environmental costs (de Castro, 2014). Although the government has recognized the costs and environmental impacts associated with hydroelectric plants, it is still set on increasing hydroelectric power.

The exploration of offshore oil and gas fields also presents important challenges to diversifying the power supply with more renewable alternatives. In November 2007, the Brazilian government announced the discovery of its "pre-salt" oil reserves containing oil and natural gas.[20] The reserves follow a rough rectangle formation with dimensions of approximately 300 km by 800 km, extending from the south of state of Espírito Santo to the north of Santa Catarina. The thick layer of salt in the subsoil indicates a large volume of petroleum. According to petroleum technicians, the Brazilian pre-salt fields could contain around 90 billion barrels of reserves, which could result in a 7.2% increase in world oil reserves (Metri, 2009). Given the difficulty in accessing these reserves, analysts predict that oil and gas resources will comprise close to half of all investments in the energy sector over the next 10 years. Critics speculate that this new source of fossil fuels may negatively affect Brazil's long-term commitment to renewable energy development. A disproportionate investment in the exploration of fossil fuels is clearly at odds with a commitment to a "clean" energy matrix (Vieira & Dalgaard, 2013, p.614).

[20] The term "pre-salt" refers to the underwater geological layer formed by the separation of the current American and African continents, a process that started about 150 million years ago. Over millions of years, large amounts of organic matter were deposited to form the present pre-salt region. See Petrobras (2017).

4.6. Contemporary Power Sector Reforms

The Brazilian electricity sector is frequently referred to as a "hybrid" system because of the present mix of private and public sector participation. In 2002, the Workers' Party, the left-wing opposition, won on a platform that included drastic reorientation of the power industry. The elected President of Brazil, Luiz Inacio Lula da Silva ('Lula'), replaced the strategy motivated by comprehensive privatization and deregulation with a hybrid model of centralized planning and market competition. After ensuring security of supply, keeping prices low was the primary objective (Tankha, 2008). While the government under the Worker's Party supported hydropower as part of its developmentalist agenda, major public support programs were created to introduce non-hydro alternatives into supply planning.

At the time of writing in 2018, the Brazilian government has invited a second wave of reforms for the electricity sector. Under the guidance of President Michel Temer, the Brazilian Democratic Movement Party (PMDB) party has developed a liberal economic platform, widely seen as a rejection of a decade of the Workers' Party and left-wing policies (Boadle & Soto, 2016). The government plans to use proceeds from the privatization program to reduce its fiscal deficit. The proposal is to expand the free market aspect of the sector by eliminating subsidies, encouraging privatization, and allowing consumers to choose their own energy suppliers. A cornerstone of the privatization plan is to auction off the electricity distribution subsidiaries of Eletrobras, the largest power utility in Brazil and formerly the state-controlled driver behind energy planning. The potential impacts of the reforms are still largely speculative. Like earlier reforms, however, critics argue that the state will lose its control over the electricity sector, and that electricity consumers will face higher prices since energy will be more commodified.

4.7. Conclusion

One key aim of this chapter was to show how the electricity system's institutional structure has co-evolved with the development of hydroelectric technology. The political and technical characteristics of the existing hydropower system shape the deployment of new technologies and serve as a defense for the status quo. While electric power reforms were technology-neutral, the characteristics and standards associated with hydroelectric power were written into the new regulatory regime. Powerful incumbent actors have also mobilized the hydroelectric infrastructure to retain their control over the industry and uphold their vision of what are appropriate forms of electricity for the country's power supply. For these reasons, the dominant energy regime has exhibited strong path dependence and lock-in (Essletzbichler, 2012, p.794). The impacts of external shocks have exposed the system's vulnerability to climatic risks and over-reliance on hydropower. Changes to these landscape factors have provided broader political opportunities to question and reshape the domestic energy system (Geels, 2002).

Furthermore, privatization and the creation of an independent regulatory agency marked a key change in the way in which Brazil managed its electricity grid. The primary purpose of Aneel was to regulate the new electricity market, insulate the reformulated sector from political intervention, and introduce professionals with technical expertise to administrate electricity issues. Under certain conditions, however, regulatory agencies can create opportunity structures that foster their status as news spaces for deliberation and policymaking (Dubash & Morgan 2012, p.270). This can happen in quite unanticipated ways by reform designers' intent on providing safeguards to investors and ensuring efficiency. The following chapter demonstrates how Aneel has prompted change in the electricity system, challenging both the tendency of large, centralized hydroelectric power and the traditional role of electric utilities.

Chapter 5

Regulatory Approaches to Wind and Solar Energy

This chapter explores the role that the federal energy regulator, Aneel, has played in enabling the development of non-hydro renewable technologies. Building on the previous chapter's socio-technical analysis of the Brazilian electricity system, I argue that the choice to develop alternative sources of energy has largely depended on how a given technology is compatible with the dominant features of the hydropower system. Within this context, Aneel has emerged as a crucial institutional supporter of wind and solar in electricity generation. The aim is to provide insights into how regulatory institutions advance renewables sources of energy in ways that are consistent with their mandates.

I begin by outlining Aneel's institutional structure, how the regulatory agency has responsibilities that deviate from conventional models for electricity reform, and the agency's role in developing renewable sources of energy in Brazil. I then describe the processes through which Aneel has contributed to the development of wind and solar energy. In the case of wind energy, which is widely seen as complementary to the existing hydroelectric system, energy regulators have strategically used their jurisdiction to mediate specific cases and contract disputes as an opportunity to improve the implementation of renewable energy auctions. For distributed solar energy, which is seen as less compatible with the electricity system, Aneel has created a new regulatory space for distributed generation technologies. I argue that Aneel's ongoing struggle for legitimacy and autonomy in the electricity sector motivated its decision-making when implementing broader energy policies and objectives.

5.1. The Brazilian Energy Regulatory Agency: Purpose and Institutional Structure

The Brazilian Energy Regulatory Agency, Aneel, was created in December 1996 as part of the privatization reforms of the 1990s. Formally enacted under Law No. 9427, Aneel replaced the National Department of Water and Electric Energy (DNAEE) and initiated Brazil's administrative engagement with public regulatory bodies removed from the traditional ministerial structures. The agency was designed around the concept of economic rather than social regulation, a distinguishing feature which pervaded the thinking around regulatory reforms at the time (Peci & Sobral, 2011). The stated mission of Aneel is to, "provide favorable conditions for the electricity market to develop in a balanced environment, amongst other agents, for the benefit of society." In practice, Aneel regulates and monitors investments in the power sector, supervising the production, transmission, distribution and sale of electricity in accordance with the policies and guidelines of the federal government (Law No. 9427, Art. 2) (see Table 3).

Aneel is formally under the umbrella of the MME but is financially and administratively independent from the government through charges levied on electricity generators and distribution companies. It is organized into approximately 20 divisions which administer different regulatory activities such as supervising generation contracts, intermediating between investors, and monitoring distribution concessions. To ensure accountability and oversight, Aneel is required to present its accounts to the Federal Court of Accounts (TCU) which are also made publically available on its website. A board of five directors is elected by the President and confirmed by the Senate for four-year terms (de Oliveira, 2007, p. 51). Aneel has relatively highly educated staff with approximately 40% of the agency's directors and upper management having a masters or doctorate (Azumendi, 2016), typically in energy planning, economics, or engineering.[21] This reflects that early reasoning that directors and staff with better training will privilege their professional careers in the face of political pressures, and have adequate knowledge to deal with technical issues.

Although Aneels' mandate is broad, it is not unlimited. Courts can reverse decisions if they find that regulators have exceeded their statutory authority, misinterpreted the law, or conducted an unfair process. In general, however, courts will defer to the expertise of the regulators when regulatory decision-making is contested (Aneel, Interview, Sept. 19, 2017).

Figure 4

Summary of Aneel's Regulatory Functions

Regulation	
Technical	• Revises the electricity tariff • Conducts Regulatory Impact Analyses (RIA) to evaluate the costs and benefits of regulatory decisions. • Creates new regulatory norms to accompany technological, economic, and environmental change.
Monitoring	• Ensures regulatory compliance from private and public agents in the electricity sector, e.g. distribution concessionaires, power generators, and transmission operators.
Mediation	• Attempts to employ conflict resolution to avoid the levying of penalties

Energy Auctions	• Implements energy auctions designed by the Ministry of Mines and Energy • Provides permits for new investments in electricity generation • Renews contracts for old power facilities and generation assets

R&D and Energy Efficiency	• Promotes energy efficiency and rational energy use • Hosts public R&D calls to encourage the development of projects that address the long-term challenges in the energy sector

*Not*e. Author's elaboration based on Aneel's website on technical information (Aneel, 2017).

[21] This study was based on a sample of 25 directors at Aneel. In comparison to other federal regulatory agencies, Aneel was ranked as the agency with the third highest level of academic achievement; the agency with the highest rank was the National Petroleum Agency (ANP). See Azumendi (2016).

Public consultation is another facet that aims to make the regulatory process more transparent and accountable to government and civil society. Aneel interacts regularly with the Senate and Chamber of Deputies during public hearings and technical meetings to summarize its activities and provide clarifications. The agency also consults with the public and gathers input prior to the establishment or amendment to any sector regulation. The main channels for public engagement are the Consumer Advisory Council and Public Hearings Advisory Council. Stakeholders can express concerns regarding tariffs and quality of electricity supply in these forums, and are represented by the five main consumer classes for energy: residential, rural, government, commercial, and industrial. In turn, public hearings are intended to give greater visibility to the agency's actions (Aneel, 2016; Peci & Sobral, 2011, p. 216). The five directors sit through hearings and listen to the evidence presented by attendees, asking questions and ruling on motions. Aneel is then obligated to analyze all contributions and integrate them into its decision-making process.

Aneel and the Ministry of Mines and Energy share the day-to-day governance of the electricity sector. Consequently, one common source of deliberation is determining jurisdiction. Since its creation, Aneel has become more involved in the siting, construction, licensing, and operation of generation facilities, especially in acquiring responsibilities for actions that had been pursued by the MME. Aneel recognizes, however, that these duties do not preclude having to collaborate with the Ministry of Mines and Energy, which has a strong role in centralized supply planning. Representatives from Aneel and the MME mentioned that they often exchange information, attempt to resolve problems together when there is overlapping jurisdiction, and provide suggestions on how to approach sectoral problems (Aneel, Interview, March 20, 2017;

Aneel, Interview, Sept. 19, 2017). While regulators and ministers may at times disagree, they claim to want to work in harmony to achieve good outcomes for the energy sector.

As part of its regulatory mandate, Aneel has a duty to comply with the social and environmental guidance from government ministers and existing legislation. Under the National Energy Policy Council (CNPE) (Law No. 9478, Art. 1), the duties required of the agency include

> …II - to promote development, expand the labor market and enhance energy resources; III - protect consumer interests with regard to price, quality and availability of products; IV - protect the environment and promote energy conservation…VII - identify the most appropriate solutions for the electric power supply in different regions of the country; VIII - use alternative energy sources through the economic use of available inputs and applicable technologies.

The breadth of this legislation provides a basis for the energy regulator to take social considerations into account. For instance, following a major energy crisis in 2001, Aneel required households to conserve electricity and reduce their consumption by 20 percent. The agency then created a public benefit fund and obligated electricity concessionaires to invest in research and development and energy efficiency programs, referred to as the Program for Research and Development (P&D) and Program for Energy Efficiency (PEE), respectively. In the case of energy efficiency, one of the obligations is to invest at least 0.5 percent of its net operations income on activities to reduce electricity consumption. Aneel sets the standards for the range of activities covered by PEE and P&D projects and has the discretion to accept or reject proposals according to pre-determined benchmarks. These programs are further justified on the basis that Aneel has the authority to search for innovations that meet the long-term technological challenges within the electricity sector (Aneel, 2017). The energy regulator thus has responsibilities that exceed the traditional regulatory tasks of rate-setting and overseeing the contracts of power concessions.

Furthermore, since restructuring, Brazilian regulatory agencies have been responsible for acquiring and organizing relevant information related to their sectors of operation. For instance, Peci and Sobral (2011, p.216) found that the Aneel board representatives claimed that the agency has more data and information than the Ministry of Mines and Energy. Aneel's ownership of sector-relevant information was also confirmed during the authors' interviews with members of the Ministry of Mines and Energy (MME, Interview, March 20, 2017). Oftentimes, Aneel provides the MME with information and data. In turn, the MME takes into consideration Aneel's suggestions for crafting decrees and legal changes (Aneel, Interview, Sept. 14, 2017). This control over sectoral information and Aneel's proximity to consumers and stakeholders has increased its importance in electricity governance.

Aneel also explicitly contributes to the achievement of other objectives that support the public interest. The independent regulator is in charge of managing the private sector, but also directs regulated utilities to perform public ends. The belief that the state had failed to manage the electricity sector made regulators partly responsible for fulfilling the social role of utilities. In this context, Brazil has experienced a new growth of public service regulations in relation to the privatized utilities (Prosser, 2000). A salient case in point is the universalization of electricity access. Since 2002, Aneel has been in charge of administrating universal service obligations. The agency requires that electricity companies serve their entire concession areas on the same conditions, which includes the electrification of low-income households and informal areas (Jannuzzi & Goldemberg, 2014). Regulators acknowledge that their role extends beyond traditional economic regulation and fixing market failure, and that their decisions can have a wider impact on the environment and society (Aneel, Interview, Sept. 14, 2017).

While Aneel is involved in policymaking, the agency prefers to highlight its impartiality in public decision-making and emphasizes its role as a neutral arbiter. Representatives have repeatedly distinguished their regulatory duties from the federal government, mainly from the Ministry of Mines and Energy, emphasizing the regulator's long-term mandate in contrast to the four-year mandates of federal administrations. Regarding electricity generation, Aneel denies accusations that it makes decisions which explicitly seek to diversify the energy supply or uses environmental criteria in its capacity as regulator (D. Rabelo, presentation, Oct. 28, 2014). In the interest of establishing their legitimacy within the energy sector, regulators tend to draw attention to their circumscribed legal role of managing contracts and reducing barriers so that projects come online within projected timeframes. Representatives interviewed at Aneel affirmed in various ways that they do not engage in public policymaking, but rather implement policies in light of their legal obligations and the MME's overarching authority to set basic policy (Aneel, Interview, Sept. 14, 2017; Aneel, Interview, Sept. 19, 2017).

5.1.1. The Regulatory Setting for Renewable Energy Policies

Aneel was founded at a critical juncture when the fundamental tenets of the original hydropower model still guided energy planning. At the same time, public support for non-hydro alternative spurred the government to invest in renewable energy. The Workers' Party government, while still convinced of the need to increase hydroelectric power, had encouraged public and private companies to generate electricity from non-hydro alternatives sources. These new public demands and alternative conceptions of power supply gained attention and began to influence expert discussions and decisions.

Within this changing institutional context, Aneel's distinct qualities and powers give it the authority to shape renewable energy policies. In contrast to the broader government bureaucracy, the professional culture of the regulatory agency has fewer ties to hydropower and fossil fuels. Although many of the agency's first employees had come from DNAEE, Aneel was an institutional newcomer which lacked many of the founding assumptions of the electricity sector. The original *electrocrats* had graduated from predominately engineering schools during the golden age of hydroelectricity and had professional experiences limited to hydropower planning, the oil and gas industry, or the distribution sector.[22] These policymakers and engineers essentially had a stake in the existing system. By contrast, the new generation of energy regulators received their educations when alternative energy technologies had already matured considerably. Technological advances in wind, solar, and bioenergy had widened the possibilities of supplying electricity with other sources of energy, and were being taught as case studies at Brazilian universities. In sum, regulators lacked many of the ideological commitments of their predecessors.

Furthermore, Aneel's quest for authority and legitimacy influences the character of regulatory governance for electricity. Regulators are agents of the state, but not necessarily of the government of the moment (Brown, 2003, p. 9). By delegating authority to regulatory agencies, electricity reforms made regulators responsible for the credibility and reliably of their sectors in the face of political pressures. Renewable energy policies in particular are discussed in reference to policy stability as an essential design element to spur investment (Stokes, 2013). While the Brazilian government seeks to achieve a variety of goals, Aneel was created to use rules, regulation, and oversight in order to manage the electricity sector. These pillars of regulatory governance stress that contracts and technical decisions made by the regulatory agency should be sustained, independent of short-term government interests. In practice, the goals of regulation

[22] Abers and Keck (2006, p.606) note that the expansion of hydroelectric utilities had stimulated the growth of first-rate university programs dedicated to training technical professional with expertise in hydroelectric engineering and related scientific fields.

can conflict with government preferences and other organizations, such as the Ministry of Mines and Energy. Government representatives might attempt to influence the electricity sector in ways that might compromise the basic tenets of regulation in order to achieve political goals.

The agency's defense of its credibility and regulatory authority is relevant to renewable energy policies. In this case, using auctions for energy supply planning can manifest as a conflict of interest between Aneel and incumbent government administrations. For large-scale power generation, the expectation that regular auctions will be held provides a guarantee to both equipment manufacturers and investors. While the MME decides on the conditions for each auction, the regulator agency fulfills the task of providing investors insight into what they may reasonably expect about long-term wind and solar auction policies, which may be difficult to guarantee. For instance, during energy crises, promoting alternative forms of energy gains support across government but loses momentum when a crisis is mitigated. The result is that government officials may be less amenable to support non-hydro renewable energy sources during periods of low economic growth, and may even pressure regulators to modify or cancel contracts for renewable energy investments when hydroelectric plants are running near full capacity. In short, government decisions based on political priorities can tread on Aneel's territory and undermine the overall quality of the regulatory framework for renewable energy investments.

At the same time, since markets and circumstances evolve over time, stability cannot mean a complete ban on regulatory changes. While the regulatory agency may decide to affirm its authority and provide a stable environment for renewable energy investments, policymakers and regulators will never be able to foresee all issues that arise during policy implementation. Consequently, there is an element of renewable energy policies that may need to be made adaptively when there is no pre-existing policy or procedure, or where policies require fuller definition. Regulators thus use their professional expertise and judgment to make incremental changes in the regulatory process. For instance, regulators often interact with energy companies, utilities, and investors to decide how they fulfill their contractual obligations in light of changing market conditions. This allows regulators to use their technical knowledge to resolve policy issues as they are encountered.

Regulators fill in the details of wind and solar policies within this political and administrative setting. They navigate the tension between stable policy and adaptive policy, providing a stable environment for renewable energy in the face of government pressures and use their regulatory discretion to influence and learn from policy decisions during implementation. Aneel also works to ensure its authority and legitimate exercise of power in co-managing the sector with actors that have other priorities.

5.1.2. Implementing Energy Auctions

Auctions are at the core of Brazil's public policy framework to increase the share of renewables in the electricity supply. Beginning in 2004, the Brazilian government created separate auctions for procuring electricity from new electricity generators and existing generators. While many auctions have been restricted to hydro, technology-specific auctions have been conducted for wind, solar, and biomass (Batlle, et al., 2010). The Ministry of Mines and Energy, in coordination with the EPE and Aneel, decides which energy sources it will admit. The Ministry of Mines and Energy and the EPE then calculate a price ceiling for each technology to ensure that participating in the auction is attractive to investors. Aneel is then responsible for the auction procedures. In the case of auctions for new energy and alternative energy, electricity distribution companies determine the demand they face for electricity over the next five years.

The exact amount of targeted energy capacity is kept secret prior to the auction in order to avoid collusion between project developers. After a preliminary round, which attempts to guarantee competition, a second stage is a single “pay-as-bid” round between all bidders that successfully passed the first stage (Elizondo, Barroso, & Cunha, 2014). The lowest bids are awarded with a power purchase agreement (PPA).[23]

Project developers who wish to participate in auctions have to fulfil several technical and financial requirements. To secure initial approval for their project proposal, wind energy projects need a valid preliminary environmental license, a grid connection feasibility report, a declaration that local content requirements are met, confirmation of land-use rights, and demonstration of financial viability (Aneel, 2015a; MME, 2016). A preliminary confirmation of a project’s viability of being connected to the main transmission grid is issued by the Brazilian Independent Transmission System Operator (ONS), or the respective distribution system operator. Lastly, project developers have to provide proof of financial guarantees. To participate in the auction, they have to deposit a bid bond in the amount of 1% of the estimated project cost. Should they win the auction, they have to deposit the completion bond of 5% of the estimated project cost (Aneel, 2014b).

Brazil’s practical experiences with auctions have been mixed. When a project bid is awarded, the project developer is obliged to build the energy facility within two to five years, depending on the auction type. Some awarded projects do not reach commercial operation by the agreed deadline or are abandoned at some point after the auction. On average, the Electric Energy Trading Chamber (CCEE) estimates that project delays occur at a rate of around 27.3%, and non-completion at a rate of 10% (Viana, 2017). This represents a major risk, since renewable energy

[23] The first auction stage is referred to as a descending clock auction. This stage ends when the successful bids are equal or lower than the capacity to be auctioned multiplied by an “unknown” factor to guarantee competition in the second stage, which awards final projects.

project delays and cancellations may lead to reduced energy security, higher wholesale market prices, and higher CO2 emissions when thermoelectric plants are run to compensate for a lack of electricity supply. Moreover, auctions are also meant to stimulate the domestic production of renewable technologies. The local industrial base for wind energy depends on a pipeline of guaranteed projects in order to plan how many turbines and related components and equipment that they need to produce; unfinished projects have an adverse impact on its operations. In sum, while auction results may initially look favorable and lower the price for electricity, they may be insufficient to propel the policy through a difficult and politicized implementation period (Stokes, 2013, p. 491).

Since auction designs with strict requirements do not necessarily translate into on-time or completed projects, Aneel is often responsible for achieving the implementation of energy projects. Aneel has three possible options to deal with the delay or cancellation of a project: the agency can oblige the project developer to forfeit the energy that was not delivered, it can issue a financial penalty or fine for not fulfilling the terms of a contract, or it can ban non-compliant developers from participating in future auctions. It is up to Aneel to decide the consequences for each individual case. For example, Aneel may grant an extension to an implementation deadline if it does not attribute delays to a developer's project management. Rather than applying a straightforward set of rules, Aneel exercises discretion in adjudicating whether or not a project developer is responsible for a non-performing or unsound project. The initial auction design stipulates the participation rules, but the way that Aneel enforces projects during implementation shapes auction outcomes.

5.2. Wind Energy

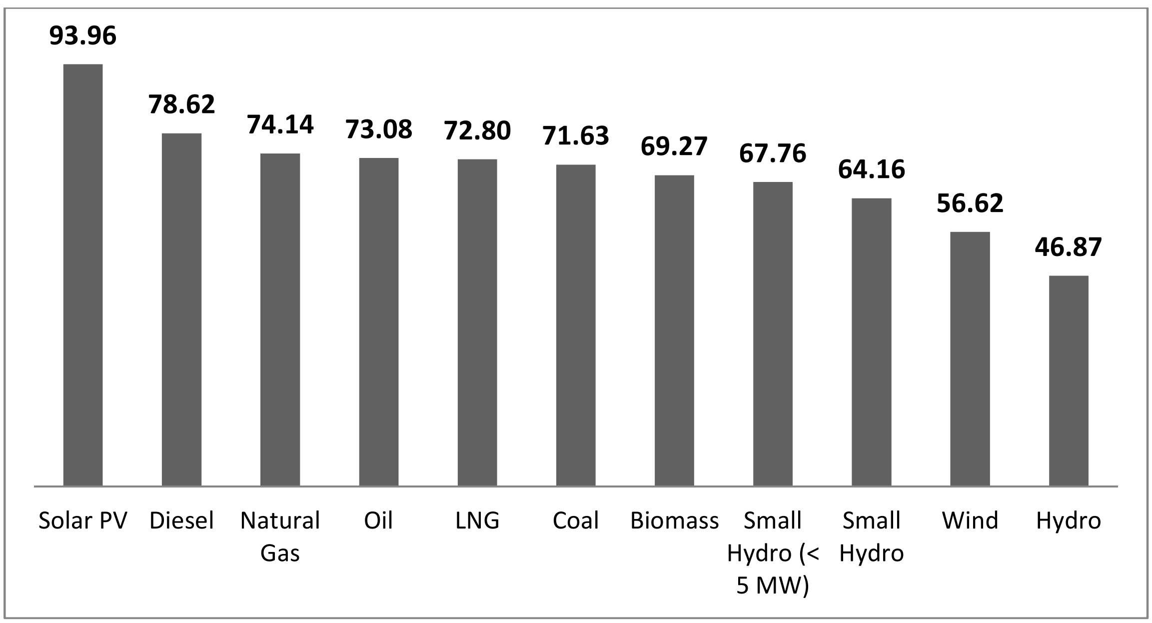
In Brazil, wind is the fastest-growing source of energy for electricity generation. By 2016, wind represented 39.3 percent of total supply growth, followed by hydropower (35.1 percent) and thermal energy (25.6 percent). According to the World Energy Council, Brazil is ranked 8th globally in terms of installed wind capacity as of 2016. It also also has the world's third lowest costs for wind power generation, behind India and China (World Energy Council, 2016). Figure 5 presents the costs of new energy capacity by source in Brazil. Wind energy has the second-lowest levelized cost, behind hydropower.

Large-scale wind generation is predominantly onshore and geographically concentrated in the Northern and Southern regions of the country. Wind parks are connected to the national electricity grid through the National Interconnected System (SIN). Although less common, wind energy can be utilized as a small-scale, off-grid systems, also referred to as "stand-alone systems," where wind turbines provide electricity to locations that are not connected to the electricity distribution system. These off-grid wind systems are typically located in remote rural or maritime regions where it is infeasible to construct transmission lines.

The evolution of government policy to support wind energy begins with the larger goal of ensuring supply security. Following the launch of the Proeólica and Proinfa programs to stabilize supply levels in 2002, Brazil's wind energy production started to quickly expand. While ANEEL's precise role and functions were still under review, the agency became involved in researching and collecting information on alternative sources of energy that could make the electricity supply more reliable. One of its tasks was to discover the physical potential of wind energy. In partnership with CEPEL and Eletrobras, a wind atlas was published in 2001, which showed that the potential capacity was around 143 GW. In particular, the wind atlas highlighted the Northeastern region for its wind potential. Through the Proeólica Program, which predated Proinfa, the regulatory agency also received several requests to license wind power generation projects, which totaled approximately 3.3 GW of power. Projects that were authorized before December 2002 were given special economic incentives because of the supply crisis underway. Aneel also began to partner with university research centers on how to develop technologies to increase the supply of wind energy (Alves, 2010).

Figure 5

Auction Prices by Technology (USD/MWh)



Note. Adapted from the CCEE (2017). Prices in Reais were updated by inflation rate from the auction day until April 2017. Then the prices were converted into USD with Exchange Rate R$ 3.28 / USD. This price differs from prices on the auction day due to exchange rate variability.

The transition to an auction-based approach to energy planning, however, has been the main tool for contracting new investments in wind energy. After the Proinfa feed-in tariffs ended in 2008, the first exclusive reserve auction for wind power took place in December 2009. A total of 13,000 MW in wind power projects were contracted. This amount was higher than the expected break-even point for the industry, which would make wind power a profitable investment. The contracted wind energy further surpassed the estimated amount of additional power capacity needed to sustain the domestic production chain, which corresponds to about 2 GW per year.

Typically, winning auction bids for wind energy have secured loans from the Brazilian Development Bank. The BNDES's subsidized rates for wind generation are about 4 percent below market rates (Hochstetler & Kostka, 2015, p.82; Melo, 2013), allowing prospective bidders to develop more competitive project proposals. To be eligible to apply for public financing from the BNDES, wind energy investors must follow local content requirements. This means that they have to source a certain share of their inputs locally as a way to develop the domestic manufacturing base for wind turbines and related equipment. After 2005, BNDES allowed a more flexible timeline for implementation of its 60 percent domestic content requirement, making agreements with individual firms that committed to moving production to Brazil. While project developers and wind turbine manufacturers highlight the challenges in meeting local content requirements, financial incentives in the form of subsidized credit have drawn international wind energy firms to Brazil and spurred firms to set up domestic production.

In terms of grid-scale renewable generation, the Brazilian government and private sector argue that wind is compatible with large-scale hydro-based electricity system. Wind energy, they claim, complements the technical characteristics of the hydropower base and contributes to supply reliability. For instance, a large percentage of wind generation potential tends to peak in the dry season. During these periods when the water levels of dams decrease and hydroelectric plants operate at low capacity, wind farms supplement the electricity supply. On the other hand, a problem of wind power is its production intermittency. The power output of a wind power plant fluctuates with changing wind speeds. These periods of low wind capacity are partially offset by the storage capacity of large hydro reservoirs in the Northeast, providing an operational flexibility that facilitates their technical and economic integration into the electricity network (Cunha, et al., 2012).

Industry stakeholders also promote wind energy as a suitable form of alternative energy. Among these energy experts are the founders of Brazil's wind power advocacy group: the Brazilian Wind Energy Association (Abeeolica). In the early 2000s, during the energy crisis, Abeeolica became heavily involved in promoting wind power. The trade group initially was composed of a small staff that represented the first wind farmers. Over time, Abeeólica grew to represent the entire production change, which includes wind farm managers and suppliers of wind turbines and equipment. According to industry peers, Abeeólica has high legitimacy in representing the Brazilian wind sector and is seen as adept at articulating a singular voice for the wind industry (Greenpeace, Interview, June 6, 2016). Representatives regularly attend trade shows and academic conferences, in addition to being present during Aneel's public hearings that concern wind industry matters.

To advance wind energy, Abeeólica and other industry supporters also promote wind's compatibility with hydropower. They emphasize that wind power is socially beneficial because it can be deployed in agricultural areas, whereby the practice of leasing the properties of poor landholders to wind project developers could present an additional source of income generation, further grounding the positive externalities of wind power. Wind towers can also be built relatively quickly, in comparison to hydroelectric dams, which fits into the perception that wind energy can accompany rapid economic development. For critics of large hydro, such as Greenpeace Brazil, wind represents an environmentally benign way of reducing dependence on hydropower without altering the traditional system (Greenpeace, Interview, July 5, 2016). Building on this logic of complementarity, the technical characteristics of wind power are seen as reinforcement to the existing regime in addition to bolstering energy security.

In sum, wind power meshes well with the goals, values, and planning of the existing hydroelectric system. In perhaps a contradictory way, the technical drawbacks of wind power are used to uphold hydroelectricity as the most ideal source of power for the electricity sector. Despite its supply advantages, wind power has quite different technical characteristics: it is intermittent and the current electricity system lacks the storage capacity for these types of technologies. Wind cannot be easily controlled. These characteristics are then used to assert that hydropower should still maintain a higher value in the energy system. In effect, the electricity industry sees the value of wind power as an "add-on" to the existing system; while wind advocates argue that the system should be analyzed as a whole, they construct their arguments in terms of the complementarity between the two sources.

The following sections illustrate how the regulatory process shapes the overall development of the wind energy sector. While policymakers and industry stakeholders justify the suitability of wind energy based on how it fits into the existing hydroelectric system, it is only through the implementation of winning auction projects that the diffusion of wind energy is a highly uncertain process. The cases of project delays caused by the absence of transmission lines and the government's sudden cancellation of energy auctions were chosen because they represent how regulators engage with stakeholders and project developers to make policy adaptively. Moreover, while auction results present low prices for wind energy initially, and support the image of a fast-growing, competitive sector, regulators shoulder the administrative costs of low-quality bids and underperforming projects. I argue that Aneel's strategies for enforcement and building regulatory credibility improve the performance of wind auctions. The case of wind energy underlines the importance of the underlying politics of the regulatory context when using auctions to contract additional capacity in renewable energy.

5.2.1. Untangling Transmission Lines (2010-present)

Beginning in 2009, the Brazilian auction model significantly increased the number of wind energy projects in the country. The results obtained in the 2009, 2010, and 2011 auctions surpassed most expectations in terms of eliciting investor interest and confirmed that wind power would be competitive with other renewable energy sources. The auction design introduced in the first reserve auction in 2009 was maintained for several years, with only minor adaptations: as long as the participation of wind energy in the electricity supply was small, public authorities did not view wind power as a source for concern in the overall planning of the electricity system. Regular auctions were organized over the following years, with only minor adjustments to the ceiling price and the types of candidate technologies that were allowed to compete with wind power in each auction (Elizondo Azuela et al., 2014).

Towards the end of 2012, as wind projects contracted during the first three auctions neared completion, the wind industry began to run into problems associated with the construction of transmission lines. When developers build energy projects, they must plan to connect those projects to the transmission grid. Prior to the intensified development of wind resources, Brazil had the practice of constructing transmission lines within two years. As power lines were extended to the northern and southern extremities of the country where wind speeds were the strongest, far from demand centers in the urbanized southeastern region, transmission lines began to take roughly four years to finish. Aneel at first estimated that new transmission lines would take approximately 14 months to be completed. Compounding these issues was the environmental licensing process which took between 48 and 60 months to complete (Abeeólica, Interview, Jan. 28, 2016; RS SME, Interview, September 23, 2016). Wind farms would be ready for operation, only to have no power lines or substations in place to connect them to the grid. As a result, absent transmission lines and substations delayed almost 70% of the wind capacity contracted in the first three Brazilian wind auctions by more than a year (Elizondo Azuela et al., 2014, p.13).

These issues alerted policymakers to a broader policy challenge: the realization of the country's wind energy potential largely depended on the development of transmission infrastructure which could move electricity from its point of generation to the point of consumer demand. The existing electricity grid had been constructed to suit centralized, hydroelectric generators, and windy sites do not necessarily correspond with the locations of existing grid infrastructure. In particular, the nation's windiest states in the Northeast often lacked transmission lines to connect wind farms with cities in the South of the country. These include the states of Rio Grande do Norte, Bahia, and Ceará, and the southern state of Rio Grande do Sul. Investors that secured winning bids in the wind energy-specific auction in 2009 concentrated most of their projects in the Northeast, the region with the highest wind speeds, expecting that adequate transmission planning would follow. The ability to export this enormous amount of wind-generated electricity across state and regional lines, however, is limited by the structure of the national transmission system.

The technical answer to this problem was the development of a more integrated model for transmission planning. A defining trait of the early design of wind energy auctions was that policy designers had integrated transmission planning into the auction process, centrally designating a network expansion plan involving a multilayered system of shared collector substations conditional on auction results. Based on this plan, the Ministry of Mines of Energy and Aneel would separately auction concessions to build the necessary transmission lines and substations, while the investor would not be liable for any delays in the interconnection of their projects. The idea behind this scheme was that, because the auctions enabled the full disclosure of projects in advance, it would be possible to achieve greater coordination and economic efficiency by centrally coordinating the planning of new power facilities and transmission lines (Elizondo Azuela et al., 2014, p. 8). In effect, because policy designers and developers had full information about project locations, they assumed that transmission would be built out to attend to this new generation. They had further assumed that transmission requirements for wind energy were equivalent to other energy projects that had been constructed previously.

To untangle the problem of creating the necessary transmission lines for wind facilities, an immediate solution was first needed to assist project developers who had had finished projects. Since many wind projects could not be delivered on time, Aneel set out to determine the extent to which delays were beyond a given project developer's control and which were affected by absent transmission lines. Without regulatory adjustments, project developers would be held responsible for being unable to deliver their energy (Aneel, Interview, Sept. 19, 2017).

Aneel frequently mediates requests for a deadline extension to postpone obligations for energy projects, avoiding resorting to stricter enforcement mechanisms, such as penalties. In addition to delays caused by environmental licensing, Aneel considers transmission grid extension a valid reason to grant a deadline extension (Bayer, 2018). The agency created Resolution 583, which set a new deadline for the awarded capacity on the basis of a delay in transmission grid extension. These new set of conditions would allow project developers to show that they had already built operational projects and fulfilled their contractual obligations, and that the only missing element was the transmission lines to link their energy production to the grid.

In addition to project delays caused by lagging transmission issues, other companies had not finished building wind farms because they had placed bids for projects that they were unable to deliver. As previously mentioned, investors often bid below an auction's price cap in order to secure an auction contract. This can lead to long-term price reductions for unconventional renewable sources of energy, but may not accurately reflect an investor's true costs to construct a power plant. To gain more time to construct their projects, some investors claimed that delays in the transmission grid connection had compromised their operations. Instead of granting across-the-board extensions for project developers who cited the transmission issue as a reason to postpone their deadlines, Aneel inspected each project on a case-by-case basis to fully adjudicate responsibility for project delays. According to an interviewee from Aneel (Interview, Sept. 14, 2017), consistency in holding developers responsible to their contractual obligations is meant to prevent short-sighted project proposals:

> In general, Aneel tries to give a very strong regulatory signal to say the exact following: only participate in an auction if you are sure that you know what you're doing. I don't want to contract some cheap project that's not going to be there, so if you're going to participate then you better have the conditions to do it…Aneel does not revise any of its contracts. So, if the exchange rate went up, that's your problem. You don't need to declare bankruptcy, so just cancel a contract, pay the penalty, and leave. Aneel does not transfer auction risks to consumers; this posture is already made very clear.

Aneel's main regulatory objective was to achieve compliance while facilitating a resolution to the transmission problem. The regulatory agency claims to first work with wind companies when attending to requests to grant extensions, but will ultimately dispute projects that are unable to follow through with their obligations. Aneel was adamant about not granting extensions to developers who could not prove that their plant operations were compromised by transmission issues. It also refused to give into industry requests to waive penalties for further delays in building transmission lines. At the same time, Aneel granted financial incentives to companies for constructing transmission facilities on time and within the existing rules and regulatory framework.[24] While a more generous approach to granting deadline extensions could possibly improve the immediate rate of implementation of wind projects, the agency reasoned that a more tolerant posture could encourage companies to relax the management of their ventures.

As Kovacic (2014) notes, much like a commercial enterprise, a regulatory agency develops a brand that signals quality to various observers. A strong reputation for enforcing regulations increases the agency's chances of achieving its regulatory priorities in the long-run. By inspecting projects that have violated a contractual agreement on a case-by-case basis, Aneel attempts to develop a reputation that signals credibility among industry participants. The agency exercises some flexibility in determining what factors are out of investors' control, but with the overall objective of achieving compliance. In this way, Aneel maintained its right to enforce contracts and punish companies to communicate that only investors that can commit to delivering projects within the scope of their contracts should participate in energy auctions. The agency conveyed that it has a low tolerance for companies that bid projects that are unable to enter into commercial operation within their original deadlines.

Aneel's efforts to brand itself as a credible regulator further enhances its power within the electricity sector. The agency's jurisdiction often overlaps the activities and responsibilities of

[24] The auction of transmission lines were prolonged until September 2016 because the sale of Celg-D, owned by Eletrobras, lacked interest from investors. Eletrobras had decided not to renew its contracts.

other public authorities. For instance, interviewees from Aneel contrast their more rigid posture with the Ministry of Mines and Energy, which they suggest takes a more “friendly” approach in responding to the complaints of industry participants (Aneel, Interview, March 20, 2017; Aneel, Interview, Sept. 14, 2017). In this sense, the Ministry of Mines and Energy can compromise the regulatory signal to investors by changing the rules of the game, or providing a more lenient treatment of underperforming projects. By spelling out that project developers will uphold their obligations or lose their privilege to participate in auctions, Aneel’s stronger “brand” as a credible regulator gives it a greater chance of being an influential actor and making decisions that affect the form and quality of competition. In effect, the regulatory signal to prospective auction participants is that there is no toleration of underperformance from low-quality bids, despite policymakers’ divergent preferences for energy policy.

In addition to disputing individual contracts, a second step to improve the implementation of winning bids was the creation of a new auction design. Aneel and the MME decided that future participation in energy auctions would require proving conclusively that projects had access to transmission lines (CERNE, 2016). The government also discontinued the centralized planning of the transmission expansion, which coordinated the construction of new power facilities with the expansion of the transmission grid. This approach had put the construction of new transmission lines into a very tight schedule with little margin for error (Elizondo Azuela et al., 2014, p. 10).

By December 2015, the MME and Aneel had proposed to couple the auctions of wind farms with the construction of transmission lines, though it was unclear how investors would view this and how it would be implemented. The MME turned to the Brazilian Wind Energy Association (Abeeólica). Owing to its close relationship with wind investors, Abeeólica would now be, in part, responsible for trying to secure nationwide transmission and thereby increase the prospects for wind investors to export energy. The trade association was asked to study a model for wind power producing companies to invest in transmission lines. According to Dr. Elbia Gannoum, the president of Abeeólica, the association created a working group to do so.

In the eyes of Aneel, Abeeólica is a legitimate participant in the process of successfully bringing wind projects to the market. An important figure in the Brazilian wind industry, Elbia Gannoum had developed her professional career at the Ministry of Mines and Energy and the Commercialization Chamber (CCEE). While the wind trade association is staffed by other former industry insiders, which could signal an opportunity for regulatory capture, the privileged voice of Abeeólica in the regulatory process is seen as counter-balanced by the regulator's public consultation process. According to Aneel (Interview, Sept. 19, 2017):

> We, here at Aneel, the entire process at Aneel is very transparent from the point of view of decision-making. Therefore, decisions are taken by superintendents after a public participation process, that is, a norm that affects any stakeholder - whether consumer or generator - it has to be in public hearing for a period, agents can contribute and this is a role of Abeeólica, in the sense of public participation and they put their contributions, obviously with the objective to foster wind generation. We, the regulator, you should know, live in an eternal conflict, because wind generators want the wind energy market to grow, and we do too, but hydraulic generators also have similar demands, as well as thermal generators - and the overall demand can only be one. You are not able to satisfy everyone. But that's normal, it's part of a healthy process.

Rather than relations between regulator and the regulated being analogous to a contract, Aneel's problem-based approach significantly departs from the hands-off and quasi-juridical style often emphasized in the literature on regulatory design (Dubash & Rao, 2008). Where deliberation and taking account of outside industry is necessary, the agency receives evidence through public audiences in addition to direct participation of stakeholders in the regulatory agency itself. The adoption of public consultation procedures ensures that as many different viewpoints as possible are made available to the regulator, earning its legitimacy through wide participation in decision-making (Prosser, 1999, p.200). Abeeólica is seen as having ample technical knowledge of the wind sector and maintaining important lines of communication with wind energy generators. Aneel argues that Abeeólica's negotiation power in overcoming the challenge of expanding the transmission system is held accountable by the agency's transparent public consultation process and the debate between stakeholders.

Following changes to the auction design, the financial risk for transmission grid delays was transferred to the project developer. Critics have argued that this transfer can lead to higher auction prices (Ferroukhi et al., 2015), which may partly explain the price increase of 9% in wind auctions held in 2013.[25] Regulators, on the other hand, argue that making such adaptations during implementation have made transmission deadlines more "realistic" and attuned with the changing context for energy investments (Aneel, Interview, Sept. 19, 2017). Previously, deadlines for wind projects were based on the time it took to complete the environmental licensing process. The fact that the time to construct long-distance transmission lines was not adequately factored into auction designs presented wind energy as much cheaper than it actually was. These information asymmetries were revealed after the first wind auctions had taken place. In deciding individual cases for project delays, regulators discovered that tying the construction of transmission lines to new investments in wind generation was infeasible. In so doing, they prompted a process that required rethinking approaches to transmission and supply planning.

Aneel's deepening involvement in managing the governance of the wind energy market has prompted regulators to better incorporate wind into the electricity system. Given the significant growth of the industry, high penetrations of wind power create variability and become

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[25] Bayer (2018) notes that the higher local content requirements and further regulatory changes could also be responsible for this price increase.

a challenge for how the electricity market operates. If wind speeds drop, other generators must be available to meet the demand and alter their output to compensate for fluctuations. This "intermittency" generates a cost for other generators that have to compensate for wind's variability of supply. The priority to deal with various aspects of wind's intermittency issues is expected to be a major focus of Aneel's 2018 regulatory agenda. One interviewee from Aneel asserted that early intervention in the intermittency engendered by wind energy ensures that renewable energy continues to be an important part of energy expansion (Aneel, Interview, Sept. 19, 2017).

Aneel has also decided to direct its R&D activities to resolve intermittency issues. For example, the use of wind energy is limited by the lack of storage technologies. In 2016, Aneel created a special call for R&D projects to integrate energy storage systems into wind and solar facilities. The idea is to integrate intermittent and unpredictable renewable energy into the grid while also creating a technological base and infrastructure for Brazil's own production of storage systems. The R&D project call would also allow Aneel to engage in the early identification of what storage technologies could be more easily commercialized (Aneel, 2017).

In summary, for wind energy, an auction process that accounts for the extension of the transmission system is of great importance. In comparison to hydropower, the technical characteristics of wind elicit a different type of transmission planning, since the best wind regions are located far from load centers. This changed context for transmission planning, however, was not factored into the design of auction contracts, but discovered through Aneel's monitoring of individual wind projects. The delays caused by transmission lines illustrate the strategy that regulators have adopted to ensure compliance while collaborating with key stakeholders to resolve regulatory problems. Aneel's reputation for enforcement and willingness to intervene in response to the industry's performance has been essential for securing its regulatory objectives (Ayres & Braithwaite, 1992). The agency incorporates stakeholders' interests and its own organizational goals to make sure that additional power capacity is built. Furthermore, Aneel's mediation of wind contracts has motivated the agency to prioritize R&D resources to anticipate issues related to intermittency.

5.2.2. Cancelling Wind Energy (2016-present)

Until 2016, Brazil had been experiencing rapid economic development. The country's energy supply was growing at a rate of approximately 4.5% a year to keep up with consumer demand. Generation firms had rushed to bid for licenses to supply the power needed to fuel growth, as a commodities-fueled boom drove annual economic growth above 7 percent in 2010. Auction winners used their long-term power purchase agreements (PPAs) as collateral to attain relatively cheap credit from the Brazilian Development Bank and other project lenders. A collapse in commodities prices in 2015, however, tipped Brazil into a recession that shrunk economic output by more than 7-percent, crippling demand for electricity. A slightly above-average rainfall in 2016 had also temporarily filled hydroelectric reservoirs, supporting the government's belief that there would be more contracted power than needed to satisfy demand.

The economic crisis and decline in electricity demand had severe impacts for distribution companies. Electricity distributors are under obligation to procure, in advance, 100% of the energy required to attend to consumer demand in their concession areas. Commonly referred to as "resource adequacy," regulators recognize the difficulty in accurately predicting consumer demand. Aneel thus stipulates that distribution companies have a modest leeway to secure energy contracts from suppliers: they are allowed to maintain a maximum surplus of electricity of 5%

above consumer demand, or they can run a deficit of 2%, or less. Given the consecutive years of high economic growth, distribution companies had contracted energy for the 2016 fiscal year based on assumptions that the economy and electricity demand would continue to expand. As the crisis escalated, it became apparent that distribution companies would be left with an excess of contracted electricity. Some distribution companies had contracted 15% above consumer demand in their concession areas. Regulators estimate that the average was 10% (Aneel, Interview, Sept. 14, 2017; Aneel, Interview, Sept. 19, 2017).

The government cited these worsening economic conditions in order to intervene in the scheduling of technology-specific auctions for solar and wind energy. A few days before the planned date in December 2016, the MME cancelled the only reserve energy auction for wind and solar, citing a reduction in energy demand for the following year (EPE, "Queda de demanda," 2016). As a result, no new wind or solar projects could be contracted. This decision was a cause of concern for renewable energy investors and wind and solar equipment manufactures. While the government does not make promises about when it will hold auctions to contract new energy capacity, the scheduling of regulars auctions allows suppliers to plan for the long-term. The local manufacturing industry for renewables had been expecting an average of 2GW of new wind capacity and 1GW of new solar capacity to be contracted each year. Canceling the auction had undermined these expectations. In response, the Ministry of Mines and Energy affirmed that the decision would not affect the country's long-term renewable-energy policies, which aims to double non-hydro renewables by 2030. The government also guaranteed that it would schedule regular tenders for renewables in 2017 (Spatuzza, 2016).

Aneel initially disagreed with the government's decision to cancel the auction. The National Council on Energy Policy, an assessor of the President of the Republic which serves to articulate the executive branch's decisions regarding energy policy, had made a unilateral decision behind closed doors. The regulatory agency has no representation on the council and was only notified two days before the government's decision (Aneel, Interview, Sept. 14, 2017). Since the auction process is led by the regulator, under the guidelines of the MME, the decision was initially seen as an instance of undue political interference, and an infringement on Aneel's autonomy. Moreover, the government and the MME's public statements had led investors to believe that Brazil would grow more and would consequently need more energy. The MME's official expansion plans, the Decennial Energy Plans, had also reported that additional auction rounds would be required to keep up with growth (MME, 2015; MME, 2016). Despite the government's reassurances that another auction for wind and non-hydro renewables would be considered for 2017, canceling the auction fomented doubts among investors about regulatory stability. The MME's unexpected shift of opinion threatened the long-term commitment that equipment manufacturers and renewable energy investors desired.

To solve the country's oversupply problem, the Ministry of Mines and Energy proposed "de-contracting" the excess energy, also known as a reverse auction. Under this type of auction, the cancellation of unfinished energy projects would take place as a competitive tender. Project developers that were awarded supply contracts in previous reserve auctions would bid for their projects to be cancelled. The project owners that offered the lowest discounts on the penalties that they would otherwise have to pay would have priority in cancelling their projects. By paying a smaller fine to return their contracts, winning bidders would preserve their investment capacity and be able to participate in future auction. They would also avoid a more confrontational dispute process with Aneel for not fulfilling their contractual obligations. With the prospect of a return to economic growth in 2017, the government hoped that a coordinated reversal of supply contracts would allow fresh investments to return to the sector as a way of "putting order in the house." In effect, the removal of poorly-managed power projects would liberate space in the supply market for new projects.

With the decision to hold the reverse auction in August 2017, regulators were worried about the message that an across-the-board cancellation of contracts could send to energy investors. While the MME had based its decisions on the country's poor economic conditions, it was initially viewed by industry participants as a retroactive change in the rules that could set a bad precedent. The proposal to amicably cancel under-performing contracts provided a means of escape for financially distressed firms that were unable to build the power projects awarded to them, particularly in the wind sector. In theory, it would make sense for the government to unload un-built projects from its balance sheet; however, by providing special conditions for underperformers, the government indicated its unwillingness to adequately discipline firms that failed in their contractual responsibilities. At the same time, it provided fewer incentives for firms that had "followed the rules" and delivered their projects within projected time frames, but were not rewarded for their good performance and might be less willing to cooperate in the future. Aneel's efforts to provide credible regulatory signals could consequently suffer from the Ministry of Mines and Energy's weaker stature towards investors.

In such an environment, often marked by uncertainties at the ministerial level, Aneel has had to sustain technical decisions that govern renewable energy. Representatives of Aneel have expressed their dissatisfaction with the government's disruptive influence on the regulatory process in both discrete and open ways. According to a representative of Aneel: "In reality, distribution companies want to get rid of their contracts. So, we have a good partnership with the government and the MME, but the agency does not give up on its competences, and will continue to follow and regulate the process" (Aneel, Interview, March 20, 2017). While representatives from Aneel were concerned about the overreach of government in their duty to regulate contracts, the agency is required to comply with decisions made at a higher level of authority. However, the fact that Aneel is at times subordinated to the decisions of the MME and the incumbent political administration does not mean it withdraws from attaining its regulatory objectives. On the contrary, Aneel's struggle for legitimacy and autonomy in the electricity sector motivates its strategy in maintaining the credibility of the wider institutional framework for renewable energy.

While Aneel initially viewed the decision to cancel contracts as a threat to the regulatory process, the political origins of the oversupply issue influenced its view that intervention was not only legitimate, but could reinforce its authority in ensuring compliance from market participants. In principle, the agency generally believes that changes in broader economic conditions should be shouldered by firms, and are not the regulator's problem (Aneel, Interview, Sept. 14, 2017). In this case, however, Aneel took into consideration that the situation had been aggravated by government interference. In January 2013, President Dilma Rousseff's administration had politically intervened to order a drastic reduction in electricity prices, which had simultaneously encouraged the increase in energy demand. As part of the government's package to guarantee cheap electricity, distribution companies had been required to participate in "emergency auctions" and contract energy from existing power plants that normally sold electricity in the free market where consumers negotiate power supplies directly with electricity generators and traders. The incumbent administration had decided on these plans with little involvement from the Ministry of Mines and Energy and Aneel (Borges, 2014).

The regulatory agency's directors, while avoiding open criticisms of the administration, expressed concern about the unprecedented practice of requiring distribution companies to contract large amounts of their energy from the free market. They were also displeased with having to rush the public consultation process to discuss the new decree with stakeholders. One of Aneel's core regulatory procedures is to hold public consultations regarding any major changes in the electricity sector to elicit the views and responses. It also provides a means for the agency to state its priorities, respond to issues raised by actors in the sector, and develop a common set of expectations. In sum, the government's intervention to provide cheap electricity infringed on Aneel's territory in supervising supply and demand in the regulated market.[26] The decision also forced Aneel to proceed in a manner that compromised its own procedural obligations.

In responding to the crisis early on, one of Aneel's first steps was to allow distribution companies to cancel contracts that they had acquired during the emergency auctions in 2014. One the one hand, Aneel's official justification was that this energy, produced primarily from hydro and thermoelectric plants, could be easily returned to the free market. Since these projects were already in operation, this approach would not put at risk projects that had not yet amortized their debt, where the banking sector would likely respond by increasing interest rates. In addition, hydroelectric reservoirs continued to have low water levels and were not operating at their full potential. The resulting high price for electricity facilitated the agency's ability to resell unwanted contracts, where generators sell their electricity in the free market and make large profits. Using this opportunity to their advantage, Aneel reversed an initiative that had compromised generation and distribution markets. In effect, Aneel was undoing one of several

[26] Agency employees have been critical of the Workers' Party administration, accusing the government of having compromised progress in the electricity sector by infringing on Aneel's autonomy and authority. See Rittner (2014).

political decisions imposed by the previous administration that had obstructed its regulatory authority.

Furthermore, until that point, there had been no formal procedures developed to deal with a mass cancellation of incomplete projects. In the beginning, Aneel provided modifications and special rules for developers to postpone their project deadlines. The agency also inspected individual projects to see whether delays fell under the responsibility of the project developer. By implementing these small adjustments, the agency was able to head off problems at first (Aneel, Interview, Sept. 14, 2017). As the agency continued to monitor the process, it noticed that it needed to broaden its efforts. Electricity distributors were holding too many supply contracts from non-performing, “problematic” projects. While these contracts remained on their books, they could not legally contract new energy from power plants that were entering into operation. Aneel created a special resolution to cancel projects that were under construction, but awaiting environmental licensing permits. This modification allowed distribution companies to trade energy contracts amongst themselves in an amicable fashion without imposing penalties for noncompliance. Since there are 63 distribution companies in Brazil, however, cancelling bilateral contracts between distributors and generators resulted in high transaction costs for the agency. On average, distribution companies contract energy from approximately 40 power plants, which meant that Aneel had to revise 40 bilateral contracts for each distribution company (Aneel, 2016).

The voluntary cancellation of supply contracts falls within the jurisdiction of Aneel and the MME. As such, Aneel and the MME partnered to create a credible framework for the reverse auction. Aneel’s procedures to modify and, in more serious cases, cancel awarded projects were intended to complement the Ministry of Mines and Energy’s friendlier auction to de-contract projects. If a project developer elected to participate in the MME's procedures, the fine was less than the penalty that would have to be paid to Aneel. The developer only had to relinquish a small part of its deposit which had been used to secure a spot to bid in the original reserve auction. Such a process was intended to give companies the option to avoid lengthy litigation. Aneel's procedures for dealing with cases of noncompliance, on the other hand, are generally less forgiving. Under the regulatory agency's rules for non-compliance, the fine to cancel a contract is higher because the developer would be deemed as having been unable to fulfill its contractual obligations. The project developer would also be barred from participating in future auctions for two years.

Conflicts and tensions inevitably arise between the MME and Aneel as they co-manage the sector. Each public authority attempts to pursue its interests and goals within the framework of the regulatory process. Yet, regulation is also intended to encourage orderly management of the sector, and both the ministry and the energy regulator have an interest in preserving the quality of participation in the electricity sector. By collaborating on the design of the reverse auction, the MME and Aneel negotiated their priorities while drawing on their competences to devise a joint solution (Aneel, Interview, Sept. 19, 2017):

> We quickly identified that Aneel did not have all the tools to solve the problem in this specific case…In this specific case of over-contracting energy, as well as reserve auctions and energy auctions, there are competences on both sides; Aneel cannot change the law or a decree, and some things we wanted to do needed it. We suggested some revisions for the ministry to incorporate, and at the same time they would inform us of some of the needs they identified, and we dealt with it. Now, the ministry cannot tell Aneel what it has to do, it can suggest, and Aneel does what it wants, in the same way we can provide suggestions for them and they just do what they want. There was a lot of talk, a lot of interaction, the overall collaboration was good, but not everything they asked us to do we did, not everything we proposed to do they did, which was normal too.

Both Aneel and the MME stood to benefit from coordinating the reverse auction process. The MME wanted to reduce the supply glut, while Aneel wanted to communicate its low tolerance for poor project management and short-sighted investments. To achieve both goals, the MME would first hold the reverse auction which would "bring order" and allow under-performing projects to voluntarily remove themselves from the balance sheet. In a second movement, once the de-contracting auction had taken place, Aneel would come in and cancel the remaining projects through its more rigid procedures for dealing with cases of noncompliance. Collaboration and reciprocity exist between two public authorities, at the same time that the regulatory process is marked by inner tensions and disagreements.

As a result, from Aneel's standpoint, the de-contracting process reinforced its regulatory authority. The overall credibility of the cancellation process depended on Aneel's more rigid approach towards enforcement. The final say on what projects would be cancelled, and on what terms, resided with the regulatory agency, since it had the authority to de-contract everyone that could be judged as non-compliant. Projects that had not voluntarily declared insolvency under the MME's reverse auction, or that had participated but had asked to pay low penalties for the right to cancellation, would be subject to entering the dispute process with Aneel. One regulator from Aneel claimed that this is where "the real conflict begins" (Aneel, Interview, Sept. 14, 2017), assuring that this was not a desirable position for project developers.

Meanwhile, the MME was able to reduce the number of supply contracts and realize other political objectives. Although not widely disclosed by government representatives, the Ministry of Mines and Energy was politically obliged to create its own de-contracting process. The Brazilian government is presently the controlling shareholder of Eletrobras, Latin America's biggest electricity generator. Furnas, a subsidiary of Eletrobras, was unable to fulfill its obligations to construct several wind energy projects. If the de-contracting process had been solely carried out by Aneel, without involvement from the MME, both Elebtrobras and its subsidiary would be prohibited from participating in future auctions for two years.[27] Denying Eletrobras the right to participate in energy auctions would be politically controversial and would severely limit the state-owned company's performance in the energy sector. The de-contracting process was thus designed to allow the MME to shield Eletrobras from Aneel's noncompliance procedures.

Moreover, the de-contracting process enabled Aneel to achieve one of its key regulatory priorities: the efficient use of public resources. The Brazilian Constitution, supported by several congressional amendments, collectively establishes the procedures for concessions and permissions for the private sector to engage in the provision of public services. This model provides a legal basis for competition in the electricity sector. For power generation, energy projects cannot be developed anywhere, but are designated for specific zones where they can be implemented based on access to natural resource potential (e.g., wind speed, solar irradiation) and distance to transmission lines and substations. In this view, areas that are set aside for power generation are considered scarce public resources. The identification of predefined locations for energy development also attempts to avoid problems related to integrating new power facilities into the transmission system. Constitutional amendments which guide activity in the electricity sector thus establish that private sector participation is not confined to efficient management, but in fulfilling the public interest of the state. [28]

[27] The Ministry of Mines and Energy was also worried that future solar auctions would not be competitive. Since only two different project developers were able to successfully build their projects, they could charge unreasonably high prices in the next auction that included solar.

[28] Art. 175 of the Brazilian Constitution: It is incumbency of the public power, according to the law, directly or through concession or permission, always through public tender, the provision of public services.

According to representatives from Aneel, one of the goals of auctions is to insist on high quality standards in the allocation of scarce public resources (Aneel, Interview, Sept. 14, 2017):

> ANEEL's interest in repealing these contracts is not only to say to the distributors, 'Look, this contract of yours was a fraud, don't trust in it anymore, go ahead and contract another one.' Also, it's to ensure that we take full advantage of the public use of the resources that we auction. What we want is for someone to use it, any private company, but if you cannot do it, I'll take it away from you.

In the eyes of the energy regulator, the cancellation of contracts was legitimate because future supply contracts would be given to more committed investors. The de-contraction process that Aneel had developed with the MME was an opportunity to pass on licenses to other firms that could build more viable projects. Thus, by freeing up public resources for potentially better projects, the agency employed a strict interpretation of the public interest to improve the quality of competition for renewable energy projects.

While Aneel continued to cancel contracts, representatives of wind and solar equipment manufacturers lobbied for the government to hold another round of auctions by the end of 2017. They claimed that they would be left with empty factories due to the absence of new auction projects. The growth of the renewable energy industry had also brought economic opportunities to poor cities in the South and Northeast, and local politicians from these regions advocated for holding new auctions. Aneel regularly meets with representatives from the wind and solar manufacturing sectors, but the agency balked at attending to industry demands in balancing its objectives for the sector (Aneel, Interview, Sept. 14, 2017):

> They [industry] talk a lot about instability, they say that they would like to have "regulatory stability." Aneel argues that we do not like and do not believe in regulatory stability, in that sense. What we like is "regulatory security." It's not possible to provide complete stability because technology is changing, the sectoral model is changing. People need to know in what direction you're heading, they need to be able to anticipate your decisions - that is security, not stability. Public hearings are a chance to accomplish this.

Investors and renewable energy equipment manufacturers tend to depict regulatory stability as the key factor that sustains the wind and solar sectors. Aneel argues, however, that the goal of regulatory stability and the means to obtain it are sometimes represented in a misleading way by industry. Oftentimes, the positive aspects of wind energy are undermined by the high financial burden of the auction schemes adopted in past years, where high-growth scenarios have led to low implementation rates and abandoned projects. Energy regulators thus argue that regulatory quality and stability cannot be equated with a framework that guarantees an accelerated pace of investments (Bellantuono, 2016). Since Aneel has to balance a variety of demands, the agency reserves the right to maintain a regulatory process that is adaptive to changing conditions. Regulators express their commitment to renewable energy investments by making regulatory changes in predictable ways, not by merely guaranteeing a high pace of investments.

In summary, Aneel's approach to maintaining regulatory credibility and compliance underpins governance in the wind industry. The energy regulator strategically used the government's decision to cancel wind energy projects in order to reassert its authority and attract more potentially viable projects to the renewable energy market. Aneel was initially skeptical of the government's decisions, but it became apparent that the reverse auction could be mutually-beneficial for the regulatory agency and the MME. Aneel was able to reinforce its reputation for being a strong enforcer that does not tolerate low-quality projects, and the MME was able to satisfy its political objectives and clear the supply market. Aneel and the MME co-manage the sector with unease, but they share their authority in ways that often leads to collaborative and responsive solutions to regulatory problems. In the end, after a process marked by conflict, the agencies achieved the shared goal of attracting more viable projects in comparison to previous years.

Lastly, building on the case of transmission planning, the regulatory work of implementing auctions is a chance for the regulator to incorporate features from the political environment into its broader strategies. In recent years, contradictions in policy have arisen between the Brazilian government and the energy regulator, where Aneel has jostled to maintain ground over its jurisdiction. In an unforeseen way, Aneel used the reverse auction to upend a decision that had infringed on Aneel's regulatory authority. The cancellation of wind energy contracts allowed Aneel to send a message that supporting the wind industry is not equivalent to unbridled growth, and that the regulator will exact responsibility from the private sector to improve participation and quality of competition in the future. Aneel used its strengths in discerning when to use compliance procedures to intervene in problematic cases, demonstrating its willingness to be tough when necessary.

5.3. Solar Energy and Distributed Generation

Brazil's estimated solar resource potential ranks among the highest in the world, and is consistently high across the country. According to the Brazilian Atlas of Solar Energy, which provides information about solar energy resources in the country, daily irradiation levels range on average from 4,500 Wh/m2 to 6,300 Wh/m2 (INPE, 2006). To provide a comparative perspective, solar irradiation in the sunniest region of Germany is 40% smaller than in the least sunny region of Brazil (IDEAL, 2017). Yet, Germany is a world leader in installed capacity for PV solar at 48.4 GW. In addition, Brazil has one of the largest reserves of quartz in the world, which can serve as a competitive advantage for the production of silicon-based solar cells and modules. These factors make the country a prime location to develop solar energy and foster a local industry for solar cell production and other equipment. Despite these favorable conditions, and a global reduction in prices for solar technologies, the implementation of solar energy has been slow in comparison to other alternative sources.

Conventional explanations for Brazil's historically scant use of solar energy have focused on solar power's costs and undesirable technical characteristics. As in the case of wind energy, the characteristics of the existing system shape how the "efficacy" of a new technology is judged (Bunting, 2008, p.174). The electricity industry and policy-makers have typically argued that solar power is too expensive compared with conventional sources and that it has undesirable technical characteristics, particularly intermittency, which severely limit its value. Furthermore, the lack of a domestic solar manufacturing sector has been a major barrier to development. Since Brazil has a small manufacturing base for solar technologies, the majority of components for solar PV systems have to be imported. This makes the solar energy sector there vulnerable to fluctuations in exchange rates.

While acknowledging the importance of these factors, the explanation for solar energy's slow adoption is based on how it relates to the socio-technical characteristics of the electricity system. When the Brazilian government decided to diversify the electricity supply with non-hydro alternatives in 2001, energy planners were presented with several possibilities of "new" renewables candidates. Under these circumstances, solar energy did not enter into an even playing field with other alternative technologies because of its lack of "technological interrelatedness" with the hydropower system. Solar energy's intermittency, unlike wind power, does not correspond to the hydrological fluctuations of Brazilian dams. In contrast, wind power was already technologically mature and seen as compatible with the existing arrangements in the electricity sector. Consequently, a stronger support policy for wind energy was initially "sponsored" by energy planners (Bunting, 2008, p.174). The early entry of wind led to a strong technological coalition which has advocated improving its competitiveness. Solar photovoltaic energy entered at a much later stage and relies on a less experienced coalition of supporters.

Furthermore, policymakers have expressed their preferences for wind energy through public support programs. The first stage of Proinfa feed-in tariffs did not include solar power, which continues to lag well behind wind power in energy auctions. Moreover, other public policies for stimulating renewable energy sources did not significantly contribute to building up the domestic solar market. In the 1990s, the Ministry of Mines and Energy had launched the Energy Development Program for States and Municipalities (PRODEEM) and Luz Para Todos ('Light for All'), federal programs which aimed to bring electricity to primarily rural or isolated communities with small-scale, stand-alone PV systems (Goldemberg et al., 2004, p. 88). However, these programs were implemented on a provisional basis and aimed at off-grid power generation. There was no intention to scale up these programs and increase the country's share of grid-connected photovoltaic systems in the energy supply.

Government officials have reinforced this more cautious approach by openly signaling their negative expectations for the sector. Policymakers have expressed reservations and uncertainties about the potential of solar energy through official documents, public presentations, and government forecasts. While wind energy has garnered 8 years of experience in competing in energy auctions, the first reserve auction which included solar power was held in October 2014 (Hochstetler & Kostka, 2015, p.83). Before the auction, the EPE had arrived at cost estimates which were twice as high as the actual market price. Policy-makers who held favorable visions of solar energy saw this as progress; however, their voices were crowded out by those who emphasized its lack of cost competitiveness. The overall message is that solar energy is not a key technology in terms of centralized renewable energy generation.

The fact that the electricity sector is managed by several public authorities and agencies makes it difficult to achieve coherence in communicating priorities about solar energy. One example is how the ministerial and planning branches of government have contributed to an indecisive outlook for solar. The plans and policy positions adopted by the Ministry of Mines and Energy and EPE provide important information regarding long-term energy priorities. The medium- and long-term scenario planning of the MME and EPE for 2016 have been optimistic and include an objective of 8.7 GW of PV installations in the 10-year Energy Plan (PDE). This is double what was stipulated in the 2015 version of the plan (EPE, 2016). Meanwhile, while the Minister of the MME may publicly express a positive orientation toward renewables, other ministry constituents can hold opposing views. This happens to be the case with the current MME President and Executive Secretary, where the latter has expressed unwillingness to maintain subsidies for alternative renewables (Greenpeace, Interview, July 5, 2016). Together, with the unpredictable scheduling of solar auctions, this does not signal a positive vision on the part of the government to attract investments in large-scale solar energy.

The lack of political sponsorship and public stimulus has largely hindered its adoption. Feed-in tariffs and energy auctions have allowed wind energy to gain a competitive advantage and benefit from increasing returns. The present challenge for solar energy is that it faces direct competition against all technologies during energy auctions, where hydro and wind power are the most cost-competitive. Policymakers have been reluctant to lower the costs for solar and, in the process, have foregone opportunities to learn about solar energy and understand how it can be inserted into the energy matrix. Solar energy is thus subject to a paradoxical situation: Brazilian policymakers emphasize the shortcomings of solar energy, while they are simultaneously unwilling to provide it with the types of supports that have driven down the cost and improved the performance of wind.

A solution to encourage solar energy development has been the establishment and subsequent revision of a national net-metering framework for distributed generation systems. From the perspective of Brazilian consumers, the growing interest behind distributed generation revolves around several issues. First, distributed generation offers access to electricity to previously isolated communities and potential improvements in energy efficiency. Secondly, smart grid and distributed generation technologies embody an alternative vision of how consumers can reconfigure their traditional relationship with utilities companies. Unlike wind energy, the decentralized nature of the technology counterbalances the longstanding model of highly centralized power generation and large investments in transmission and distribution. Therefore, public support for distributed solar energy is based on the prospect of increased choices in energy services and independence from traditional utilities. Advocates emphasize the ideological act of unplugging from large utilities companies which encourages individuals and households to take responsibility for their own energy decisions (Greenpeace, July 5, 2016).

Although a variety of renewable energy sources are eligible under net-metering regulations which guide distributed generation, they were essentially designed to stimulate solar power generation. Solar photovoltaic (PV) systems represent more than 70% of distributed generation connections in Brazil (Aneel, 2018). Therefore, the overall focus of this section is on small-scale solar PV systems.

5.3.1. The Formative Period of Distributed Generation (2008-2012)

Until 2008, the Brazilian electricity market had been dominated by centralized generators and rules and regulations co-evolved with this technology. The electricity system's supply-side focus led to a dominant perception about what constitutes a power station: that they should be controllable, centralized, increasingly larger over time (Bunting, 2008, p. 172), and preferably powered by hydroelectricity. However, small-scale solar generation systems are decentralized and owned by electricity consumers.

The initial motivation to create a more supportive intuitional environment for distributed generation systems came from within Aneel and began as an internal discussion. A small group began to debate the possibilities of distributed generation for the electricity sector. Representatives from Aneel described the process as "bottom-up," initiated by about four or five agency employees who were eager to study the issue (Aneel, Interview, March 20, 2017).

The opportunity to transform Aneel's regulatory interest in distributed generation into a real-world application of the technology arose on pig farms located in the Southern state of Paraná. The first major experiment with small-scale generators for grid-connected electricity production was a biogas project in the state's Western region. While Paraná has a high concentration of urban industrial activities, especially near the metropolitan region of Curitiba, the rest of the state is characterized by a strong agri-business sector. In particular, Paraná ranks third in Brazil in terms of swine production. In addition, many agricultural businesses in Western Paraná are located near the waterways that feed into the reservoir of the Itaipu hydroelectric dam, the pride of Brazilian hydrological engineering and the largest generator of hydroelectricity in the world.

Given their proximity to the Itaipu reservoir, the business operations of Paranense pig farms became a major environmental liability. Brazilian scientists from Embrapa (The Brazilian Agricultural Research Corporation) and managers at Itaipu were increasingly aware that the waste generated from the local animal livestock was contaminating the dam's water resources.

To mitigate the impact on water quality, Itaipu Binacional, the operating company of the Itaipu hydroelectric plant, formed a partnership with Copel Distribuição, the local distribution company, as well as agricultural cooperatives, to devise a solution. Their proposal was to install biodigesters on the adjacent properties dedicated to swine production as a way to lessen the environmental impact of livestock refuse on the reservoir, and to study the economic and technical feasibility of bioenergy. The idea was to use the methane gas produced by the decomposition of organic matter to generate on-site electricity. Farmers and agricultural cooperatives saw this as an opportunity to reduce the high costs of electricity necessary to maintain their business operations. Any surplus electricity not used during swine production would be injected into the grid and sold to Copel (Copel, 2009).

The task of integrating small-scale biogas units into the broader electric power system presented many challenges for Aneel and project developers. A "mismatch" existed in the operational rules for electricity generation (Negro, Hekkert, & Smits, 2007): the regulations governing the installation of grid-connected generators had not yet accounted for the characteristics of small-scale units. The operating standards which were designed for large-scale central power generation required extensive information and monitoring so that electricity could be transported, sold, and distributed to final end consumers. For a number of reasons, the adoption of distributed generation technologies depended on corresponding changes to the regulatory framework.

First, to receive authorization to supply electricity to the grid, all grid-connected generators are required to install a meter to monitor the amount of electricity produced and establish a corresponding price. The central systems operator, the ONS, then uses this information to dispatch electricity and satisfy demand across the transmission network. Under existing rules, Copel would have to install electricity meters to monitor the energy produced from the first 41 small-scale biodigestors. These meters would also have to be connected in real-time to computers located in the nearest headquarters of the systems operator, the ONS. Metering systems for conventional generators have complex functions and are expensive. In comparison, distributed generation systems owned by electricity consumers generate much less electricity and can operate on an independent, stand-alone basis if desired. The total installed capacity of the Copel micro-generators was 80 kW, implying that they could produce approximately up to 0.027% of the electricity of an average 30 MW grid-scale power plant. The comparably small output of the biodigester units thus did not merit the technical costs and regulations imposed on large-scale generators.

Second, the current laws and regulations had been developed to mitigate the operational risks and volatility associated with large, centralized hydroelectric plants. In contrast to the concept of installed capacity, which is the maximum output of electricity that a generator can produce, the "physical" or "assured" energy for a power plant is a way of guaranteeing, throughout the life of a power plant, that the final output will reach the levels stipulated under a purchase agreement for electricity (Aneel, 2005). The overall purpose of this second measurement for output is to internalize worst-case scenario conditions, when unfavorable periods of below-average rainfall result in the low productivity of hydroelectric generators.[29] This system was intended to improve the economic competitiveness of the hydropower system by providing a long-term guarantee for investors despite prolonged periods of unfavorable weather conditions. Unlike the conventional generation market, it does not make sense for small-scale generators to provide these kinds of supply guarantees. For small-scale, consumer-owned

[29] Aneel calculates the assured energy in accordance with a statistical model based on average rainfalls, water flows of rivers and water levels in each plant's reservoir over a multi-year time frame. Aneel then guarantees this assured energy by issuing a certificate during the licensing process for each power plant, which it reviews every 5 years.

systems, the distribution company automatically purchases electricity that is injected into the grid based on a pre-established compensation system. This eschews the types of negotiations that normally occur when utilities buy and sell energy. Moreover, small-scale systems do not present the electricity system with supply risks based on hydrological fluctuations.

This initial phase of project development revealed that the regulatory environment was ill-adapted to small-scale energy systems. Consequently, the successful implementation of the biogestion project depended on the creation of regulations which took into account the institutional and technical needs of the new technology. Aneel began to discuss what regulators could do to facilitate it. It recognized that, with some adjustments, the project could largely operate within the existing regulatory framework. At the time, it viewed its role as limited to providing the necessary regulatory clarifications and easing standards for small-scale systems so that the project could move forward (Representative of Aneel, March 20, 2017). Regulators chose to reinterpret existing laws and regulations as a means to create a separate regulatory space for distributed generation. Electricity reforms had legally established the concept of the "auto-producer" in 1996, which authorizes private entities to generate electricity wholly or partly for their own use and consumption (Brazil, 1996).[30] The framework for distributed generation was thus fashioned out of the concept of an auto-producer. Redeploying this existing concept allowed regulators to avoid directly challenging the existing institutional structure.

To accomplish these aims, Aneel simplified the metering scheme and authorized Copel to purchase only the energy effectively injected into network, rather than having to derive a "physical guarantee" for each system. Energy producers were also authorized to use the distribution system at a 100% discount, and were not required to pay the typical usage fee of

[30] Brazilian Constitutional Decree No. 2003, September 10, 1996.

transmission and distribution lines to the distribution company. Following these modest regulatory modifications, Aneel granted authorization for the biodigester projects in July 2008.

Aneel's next step was to generalize these regulatory changes to other small-scale installations. The information and experience gathered from the Copel pilot project served as an initial basis for a framework for distributed generation. In scaling-up the biodigestion experiment, Aneel mandated that these small systems of "reduced capacity" did not have to undergo a more comprehensive and lengthy licensing process required of large-scale generators.[31] Energy regulators grounded their decision in the observation that these systems were of such small scale that they mainly posed questions for how to regulate the injection of excess electricity into the grid. Distributed generation was still a niche technology. If distributed generation was eventually used on a wider scale, this would require that regulators design a new rate structure, a lengthy and time-consuming process. They would also have to consider how these new technologies would affect the relationship between utilities companies and consumers.

As biodigestors in Southern Brazil began operation, the development of regulations for small-scale systems was consolidated as a key agenda item. Every two years, Aneel makes available on the Internet its "Indicative Regulatory Agenda." The Regulatory Agenda is essentially a list of Aneel's priorities and emerging topics that require more extensive regulations or procedural improvement. It is one way that the agency tries to make more transparent the ongoing changes to regulations to industry stakeholders and consumers. The Indicative Regulatory Agenda for 2010 included, among other items, the following language: "To diminish obstacles that prohibit the access of small electric generators to the distribution system" (Aneel, 2010). The experience that regulators had gained with the implementation of the Copel

[31] Aneel Resolution 390, of 2009, established that generating stations with power equal to or less than 5,000 kW do not have to be licensed by Aneel since they can be treated as generators with reduced capacity. This resolution builds on provisions of Article 26 of Law 9,427 of December 26, 1996.

biodgestors made distributed generation a priority item. It had generated internal learning about the institutional and technical needs of the technology, which regulators judged to be relevant in prioritizing their ongoing regulatory activities.

The growing niche for distributed generation prompted Aneel to fine-tune the technology to a wider user base. The success of the Copel project had led other organizations to make requests to install small generation units. For instance, the IDEAL Institute, a prominent energy consultancy and think tank in Latin America, wanted to install solar photovoltaic systems on the football stadiums that would host the 2014 World Cup games in Brazil (Aneel, 2010). The PV solar systems would then sell their surplus energy back to the grid as a model for sustainable development and energy efficiency. Such visible projects would use distributed generation systems in ways that would have much broader ramifications for society and the electricity system. Moreover, while many net-metering systems were under 2 MW, Aneel was interested in bringing small-scale systems with higher levels of power generation into the electricity market. In the Brazilian supply system, electricity producers with capacity above 5 MW are allowed to commercially sell their electricity to the grid. There were no regulations that enabled the installation of generators that fit into the range of 2 to 5 MW. To attend to these demands, Aneel would have to respond with more supportive criteria to consolidate the regulatory framework.

To begin a formal regulatory review, the agency's directors needed to collect information and conduct a formal Regulatory Impact Analysis (RIA) about the barriers and alternative policy solutions that existed to enable the broader diffusion and uptake of distributed generation systems. Aneel first decided to hold a public consultation process from September 2010 and April 2011. Stakeholders within the electricity sector sent their concerns about distributed generation systems and net-metering. Aneel received an estimated 900 technical contributions.[32] According to an interview with a representative of Aneel, these preliminary steps further represented a contemplation of the agency's authority and its role in supporting this relatively new technology (Aneel, Interview, March 20, 2017):

> We created a technical note with a bunch of questions, we wrote 33 questions to collect from society: Are you interested? No? What are some barriers that you think exist? And so we went on from there to investigate more broadly - technical barriers, economic barriers, regulatory barriers, legal barriers…we raised a number of issues. With the responses we received, we filtered through them to see what fell within the authority of Aneel, and what laws and decrees needed to be changed. If it's not our place to change something, could we propose the change? And from there we identified barriers that we could diminish. So the initial objective was to reduce barriers, it wasn't necessarily to incentivize: whoever wants to do it can do it and we'll create the conditions.

This first review allowed Aneel to continue to learn from extensive user and stakeholder input about the performance, effects, economic viability, and social desirability of distributed generation technologies. It then applied this knowledge to create new regulations that were needed to further the development and rate of application of the technology.

Notably, this early stage centered on framing distributed generation as a regulatory solution, rather than as a policy issue. The impetus to advance distributed generation could theoretically come from three main actors within the electricity sector: Aneel, the Ministy of Mines and Energy, or the Brazilian National Congress. The Congress can approve laws which affect the electricity sector without having to consult the MME or Aneel. Given the low priority of distributed generation in the broader political agenda, it was unlikely that Congress would take up the issue on its own. Alternatively, the MME co-manages the electricity sector with Aneel and could emerge as a potential advocate for distributed generation. Historically, energy authorities at the MME have seen their role in the sector as promoting energy expansion,

[32] Public Consultation No. 15, and Public Audience No. 42, respectively.

primarily by encouraging the construction of large hydro and thermoelectric plants. The MME's experience with smaller systems was limited to installing stand-alone generators in remote communities, and had shown little interest in distributed generation. Thus, a gap in policy action created an opportunity for Aneel to claim control over distributed generation as an emerging regulatory area.

Aneel further opted for a net-metering scheme to compensate system owners for the electricity they added to the grid. An alternative solution debated at the time was to implement a feed-in tariff (FIT) approach. FITs have been a common approach to subsidize the costs of renewable energy and distributed generation systems, especially in Europe. Any government subsidy, however, would require a corresponding law, and proposing a new law lies within the domain of the Ministry of Mines and Energy. Such an approach might result in sharing control for the development of distributed generation with the MME. Moreover, the energy tariff has been historically high in Brazil, and any cost-increase argument to accommodate the subsidy would be politically infeasible. The creation or revision of a constitutional decree would also be a costly and time-consuming option involving authorities external to the agency. A comprehensive net-metering framework with special benefits for interconnection was chosen as an alternative to a subsidy. The development of a net-metering system would allow the regulatory agency to shape distributed generation through the regulatory process.

In laying the groundwork for net-metering, the regulatory agency anticipated that the incumbent utilities would attempt to resist or block the introduction of distributed generation systems. In general, utilities companies often have little incentive to grant access to the network. Distributed generation is perceived as a threat to utilities' profits by reducing consumer demand. At the same time, utilities companies are responsible for maintaining and monitoring the grid infrastructure and can establish their own connection requirements. For instance, although the generator would be owned and managed by a utilities customer or third-party operator, the utility would ultimately be responsible for the overall grid connection, as well as the routine operation of the meter and related equipment. The distribution concessionaire would also be required to periodically collect data from distributed generation customers and provide this data to Aneel. The regulatory agency feared that utilities companies would try to discourage the use of distributed generation systems by setting more prohibitive technical requirements for metering systems.

After extensive review, the policy milestone for distributed generation was established as a net-metering framework in April 2012 through Normative Resolution nº 482/2012 (Aneel, 2012).[33] The new rules allowed small-scale, renewable generators up to 1 MW capacity to be interconnected to low and medium-voltage grids. They could then sell a surplus of the electricity back to the national grid in return for credits to offset their electricity bills. Credits earned by the micro- or mini-generators would expire after 36 months from the invoice date. Qualified sources included solar, wind, biomass, certain types of cogeneration and small hydro sources. Aneel also created a set of requirements for metering systems to limit grid operators' ability to block small-scale systems owners from connecting to the grid. In this case, the net balance of generated and consumed power would be evaluated by a bi-directional energy meter. This resolution fixed an 8-month adaptation period, so that the regulation would start to take effect in December 2012. The adaptation period provided distribution system operators the opportunity to revise their service standards and connection requirements in compliance with the general rules defined in

[33] Resolution 517 was an amendment to Resolution 482 and took affect in December 2012. However, the hallmark regulation for distributed generation continued to be referred to as Normative Resolution No. 482, or simply "482" in the vernacular.

Brazilian Distribution Grid Code (PRODIST) (Mattar et al., 2015), which defines technical standards and processes for power distribution.

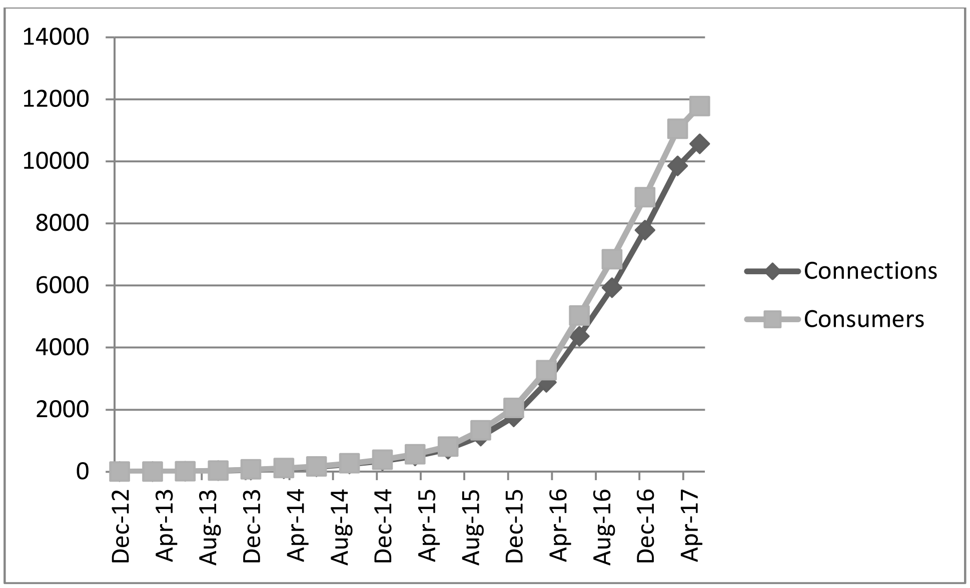
The passage of Resolution 482 established the minimal regulations to start a distributed generation market. The agency accomplished the immediate regulatory goal of simplifying the interconnection process to improve the integration of small-scale renewable energy generators into the grid. A partnership between regulators, industry, and swine farmers to experiment with biodigestion was the starting point to acquire the learning and experience necessary to construct a general regulatory framework for small-scale renewable energy generation. Furthermore, the regulatory agency had asserted that the development of distributed generation was a regulatory issue. By adopting a net-metering scheme that did not require the involvement of other public authorities within the electricity sector, Aneel claimed a discretionary space in which it could define the character and pace of distributed generation. Focusing on the consumer-side of the technology, the agency also made it clear that distribution companies would have to adjust their operations to accommodate these new technologies.

5.3.2. Expanding the Market for Distributed Generation (2012-2016)

In the beginning, the number of distributed generation installations grew more slowly than regulators had predicted (see Figure 7). The final touches to the country's net-metering framework had taken place against a backdrop of high electricity prices. By the end of 2012, Brazil was experiencing yet another severe drought that had reduced water levels at hydroelectric dams, requiring the country to import liquefied natural gas to fuel costly gas-fired generators that needed to run at full capacity. Short-term energy prices had roughly quadrupled between September 2012 and January 2013, providing a boost to the attractiveness of installing distributed generation systems. Unexpectedly, in late January 2013, the government mandated a sudden and drastic reduction in energy tariffs. During a national radio and television broadcast, President Dilma Rousseff announced a cut in energy tariffs of 18% for residential consumers and 32% for industry. The measure was made possible through an agreement with power transmission companies. They accepted the price reductions provided that the government paid retroactive compensation for improvements made to the electricity network before privatization reforms in 2000 (Monteiro & Moraes Moura, 2013).[34] These cheaper electricity prices attenuated the incentive to install distributed generation systems.

Figure 6

The Growth of Distributed Generation Connections and Consumers Receiving Net-metering Credits (2012-2017)



Note. Adapted from Aneel (2017a).

[34] The compensation was calculated in R $ 62.2 billion in 2017 [58] and will be diluted in the consumer light bill until 2025. The opposition accused the presidential election official of claiming that it was a maneuver to reduce the light bill on the eve of the 2014 presidential campaign. Consumers experienced an increase after the elections

In spite of this unfavorable environment, Aneel continued to take a proactive approach to the nascent industry. The average time to recover expenses from investing in a photovoltaic system had risen, but Aneel remained optimistic. The attitude of the agency was to keep pushing for distributed generation, despite its reduced economic viability and the government's intent to keep energy prices low: "Was it reasonable? Was it difficult? But, was it still possible? If so, let's keep moving forward" (Aneel, Interview, May 20, 2017). Regulators were not discouraged by external forces that had made small-scale systems more costly, but rather resolved to iron out ongoing issues.

The 2014-2015 Regulatory Agenda had scheduled the next public hearing to initiate the regulatory review of distributed generation regulations for mid-2015. In the lead-up to the review, Aneel monitored the roll-out of net-metering regulations to learn how to best accommodate the characteristics of distributed generation technologies. Aneel hosted a conference in Brasilia in April 2014, entitled "Micro and Minigeneration Seminar – The Impact of Normative Resolution nº 482/2012" (Aneel, 2015). Regulators were interested in gauging the wider barriers to the adoption of distributed generation systems. The agency also reviewed data collected by utilities companies. Most of the issues that surfaced were related to the connection requirements for joining up distributed generation systems to the electricity grid. On the one hand, the agency acknowledged that, in some cases, these barriers derived from the new experience that distribution companies were facing in dealing with this paradigm shift. On the other hand, even subtle forms of utilities' noncompliance could dampen regulatory momentum for distributed generation. To address these problems, Aneel first analyzed whether distribution companies' connection practices were in compliance with the standards defined in the PRODIST distribution and transmission code. Regulators also examined what they could do to remove unnecessary connection requirements that were required of larger-scale power plants. This included exempting small-scale solar PV systems from environmental licensing procedures (Mattar, et al., 2015).[35]

Apart from testing the viability and social acceptance of the new technology, the advent of net-metering set in motion the building of a constituency behind distributed solar energy generation. For the new technology to gain ground, technology-specific coalitions needed to be formed and to engage in wider political debates in order to gain influence (Jacobsson & Lauber, 2006, p. 259). In 2013, the official trade association, ABSOLAR, was founded to coordinate and represent the interests of the budding solar industry (ABSOLAR, 2017b). The founders recognized that they needed to perform lobbying activities in order to grow the solar and distributed generation industry. According to a solar professional and fellow board member of ABSOLAR (Solar Consultant, Interview, Aug. 6, 2016):

> …We are really trying hard to penetrate Brasilia. What we have done, it's ABSOLAR that was created to do this. It was created to do lobbying. At the end of the day, you cannot leave it all to this, and as painful as it sounds: if you don't have someone getting paid to go to Brasilia and visit the guys, forget about it, it's not going to happen… That's what, I think, was one of the few mistakes I made in ABSOLAR, was to criticize the need of generating cash flow for the Association. I was like, 'Man, this is an association. No one is meant to be earning money here, you know.' But no, we need to have a lot of money because we need to decide today, to jump in a plane tomorrow to go to China and meet our president in a conference...You got to do it.

Before joining ABSOLAR, the interviewee had ample experience in owning a company that installed residential and commercial solar panels. While having a vested interest in the industry's growth, he initially viewed the concept of lobbying to promote solar energy with reservation. As he gained experience in the association, he realized that developing a relationship with regulators

[35] Most distribution systems operate in a radial configuration - that is, the power flows only in one direction. The installation of distributed resources not only alters the general topology of the system, but the power flows in multiple directions. This has important implications for the protection of the system.

and providing an organized voice for solar and distributed energy was important to cultivating the institutional set-up of the industry (Solar Consultant, Interview, Aug. 6, 2016).

Moreover, according to the interviewee, the founders of ABSOLAR recognized the need to invite industry professionals with diverse backgrounds to steer the association. In addition to core stakeholders from the distributed generation sector, the board of ABSOLAR has representatives from regulated electric utilities and mangers from more traditional companies that focus on centralized generation (ABSOLAR, 2017a). The reasoning was that, if the primary aim of their work was to grow the market, which depended on both newcomers and incumbents, the association's representatives should come from different sub-sectors of the electric power industry. The well-being of the industry should not be risked because of benefits that might stem from being exclusive or favoring certain stakeholders over others (Solar Consultant, Interview, Aug. 6, 2016).

Other actors whose objectives aligned with renewable energy and small-scale generation came forward to advocate for more favorable conditions for distributed generation. The IDEAL Institute is a non-profit organization which promotes the development of renewable energy in Latin America. Associated with the German Corporation for International Cooperation (GIZ), an international development agency, the Institute has managed several initiatives to disseminate educational materials and promotional events that encourage solar energy in Brazil (IDEAL Institute, 2017). Greenpeace Brazil is another environmental organization that has emerged as a strong proponent of small-scale solar. Historically, the organization had been a vocal watchdog of hydroelectric dam construction in the Amazon, and has lobbied against the use of coal-fired thermoelectric plants. Distributed solar generation fit into the non-profit's mission as being a far less harmful and more sustainable way to generate the country's energy. Greenpeace Brazil's

Climate and Energy division has also been active in producing research and policy whitepapers on how to increase the economic viability of solar installations, such as by eliminating state value-added taxes and providing discounts on municipal property taxes (Greenpeace, Interview, June 5, 2016). Greenpeace representatives regularly attend Aneel's public hearings and technical meetings on net-metering regulations to contribute their perspective.

The Greenpeace representative also underlined the importance of lobbying and forming a single voice to present to the public and decision-makers. For instance, organizations that support distributed generation have been internally divided on several issues. This disagreement stems from advocates who believe that the sector should focus on distributed generation more broadly, represented by a variety of energy sources, or by using distributed generation regulations as a means to promote solar energy (Greenpeace, Interview, July 5, 2016):

> The wind energy lobby is very strong, they have a strong presence in the national congress, and they are an association that has a lot of legitimacy. I think it's more complicated, for example, for solar energy, because it's a very new sector. We have today ABSOLAR, but, for example, there exists a questioning of this association's legitimacy…I think it's problematic that, in the context of lobbying, to be forming blocks of networks, because if you're not able to secure a singular voice within the sector, you show that that sector is still fragile. And so, for public policy-making, this is very negative. So, I think having a strong lobby is good.

Comparing distributed generation to the wind energy sector, which has an arguably more mature coalition of supporters, the Greenpeace representative stated that an underlying tension is whether regulations favor a particular source of energy. While distributed generation is dominated by PV solar installations, the biomass and biogas, small hydro, and wind lobbies also want their smaller generation systems to qualify under net-metering regulations in order to expand their access to markets. The inclusion of different technologies has enlarged the number of stakeholders that support distributed generation, but has also brought in different groups that have diverging priorities. Greenpeace acknowledged that they have had an important role in serving as a moderator and negotiating these differences between different stakeholder groups. The progress of distributed generation have thus depended on consensus-building and emphasizing overlapping interests between members in order to make a strong case in the regulatory arena.

Despite different beliefs and prerogatives among actors, these organizations and interest groups formed a broader advocacy coalition to advance the belief that solar photovoltaic energy and distributed generation were the answer to wider policy concerns. Distributed generation has been argued to be not only a more sustainable way for consumers to produce their own electricity, but is also an alternative to the longstanding model of large-scale energy projects. In addition to providing more independence from traditional distribution companies, which are generally regarded by the public as unresponsive and inefficient, small-scale systems and installation companies counterbalance the large construction companies that have embroiled the country in corruption scandals. Small-scale electricity generation fits into a vision in which Brazilian citizens have the ability to counteract corruption and maintain a critical distance from government (Camargo, 2017).[36] This view has been echoed by both Greenpeace and supporters of small-scale solar energy (Greenpeace, Interview, June 5, 2016; Solar Consultant, Interview, Aug. 6, 2016). For example, like many supporters of small-scale generation systems, the ABSOLAR representative was against the ongoing construction of large-scale dam projects, which were often built in environmentally vulnerable areas by private construction companies. Consequently, his perception that corruption is influenced by private interest groups, which

[36] In addition to newspaper articles that draw connections between corruption and large-scale energy projects, it is also common for solar energy installation companies to argue that one of the underlying benefits of distributed generation is its ability to reduce corruption. Providers of small-scale energy systems have strategically used anti-corruption discourse to promote distributed generation’s advantages.

encompasses the electricity sector, negatively affected his outlook of lobbying in the policy-making process.

As the coalition behind solar energy grew, Aneel was nearing the date in which it would have to begin the formal revision of distributed generation regulations. Fortunately, by 2015, this timing coincided with a drop in global solar prices, as world installed capacity soared and Chinese solar panel producers entered the market. A more favorable exchange rate had also momentarily diminished the costs of importing solar energy technologies, PV modules, and related equipment. The doubts that still lingered about the realistic potential of distributed generation were also assuaged by the growing domestic experience with solar technologies and distributed generation. Solar panel installers had emerged to meet the growing consumer demand. It became apparent that solar energy systems could be made accessible to a wider base of consumers.

From its interactions with industry groups and stakeholders, Aneel decided that more robust changes to regulations were needed to expand the distributed generation market. The agency had already created the basic conditions for net-metering to take root and current market conditions gave it an opportunity to decisively foment market growth. The internal debate within Aneel centered on the agency's authority to consolidate its jurisdiction over this emerging policy area (Aneel, Interview, March 20, 2017):

> The structure of the agency is a little more dynamic, so we observed that we had a space in which to act…Realizing that there still wasn't much action from either side of the aisle, as I said a while back, we studied the issue further and identified that there was a gap there, and so we asked ourselves, could we act on it? First we consulted our legal counsel to see if it was within our jurisdiction to do it, and the response was a positive "yes." Aneel has the authority to promote energy efficiency and renewable energy sources, so let's go down this road.

Regulators used their discretion to become more proactive in defining the agenda for distributed generation. To make this case credibly, they had to demonstrate a clear and defensible set of procedures on which to make their decisions as to how they could act. The broad regulatory remit of promoting energy efficiency and alternative energy technologies allowed Aneel to justify its decisions within the existing regulatory framework and, at the same time, affirm its evolving authority over the issue. The fact that no public authorities in the electricity sector took control over distributed generation facilitated Aneel's ability to act responsively and enlarge its scope of responsibility for net-metering.

In the regulatory arena, opposition to changes in existing regulations has centered on the ways in which net-metering impacts concessionaires. As previously mentioned, electric utilities have contended that their financial viability would be undermined by distributed generation, since it would imply selling less electricity to consumers. They have expressed reluctance to adapt to the new model in various ways. Leading up to the 2015 revision of net-metering regulations, distribution companies had been largely reactive and non-compliant. For instance, distribution companies were known to cause delays in connecting systems to the grid. Although connection times have varied by distributor, Aneel estimated that the average connection time between 2013 and 2014 was 160 days, although cases had existed where delays were over 400 days (Aneel, 2015). Distribution companies also argued that net-metering consumers used distribution networks without paying a fair price to connect their systems to the gird, also known as the Transmission and Distribution System Use Tariffs (referred to as "TUST" and "TUSD", respectively). A significant part of the regulatory debate thus focused on how to increase compliance and to clarify the interconnection method for distribution operators and net-metering customers.

Before the passage of the new regulations, a final public hearing in December 2015 allowed stakeholders to express their concerns and provide information to Aneel. Stakeholders who favored a more progressive interpretation for Resolution 687 argued that distributed generation was becoming popular among consumers and had broad benefits for the environment. They also invoked the concept of consumer rights, and were concerned about amplifying net-metering benefits for various subgroups of consumers that might be excluded without additional regulatory provisions. In addition to residential consumers, Brazilian telecommunications companies, such as Oi and Claro, were interested in distributed generation to reduce their operational costs, of which electricity is the second largest item (ABRADEE, Interview, March 20, 2017). On-site distributed generation provides less costly power that can serve as a backup and keep telecommunications systems online when grid power is unavailable. In effect, while different consumer classes represented their interests, the result was a positive turn-out of eligible electricity consumers which formed part of a larger market for distributed generation systems. Together, these different industry and consumer groups demonstrated a collective stake in expanding the market for distributed generation.

In the other corner of the regulatory arena, incumbent utilities were organized through a trade and lobbying group called the Brazilian Association of Electricity Distributors (ABRADEE),[37] which represents 99.8% of distribution companies.[38] At the final public hearing to discuss the resolution, ABRADEE contested the revision of Resolution 482, arguing that Aneel was overreaching its constitutional mandate (ABRADEE, 2015). In opposing the policy

[37] The Association was created alongside the establishment of the Distribution Committee (CODI) in August 1975, and was later reincorporated in 1995, at the commencement of electricity privatization (ABRADEE, 2017). It is thus one of the oldest industry groups in the Brazilian electricity sector.

[38] A few municipal utilities in Brazil are politically represented by a separate association, the Brazilian Association for Small Electricity Distributors (ABRADEMP).

change, utilities did not make their case based on a threat to their business model and earning profits for shareholders. Instead, ABRADEE argued that distribution companies were being called on to shoulder the costs to incentivize distributed generation, since distributed generation users did not have to pay to use the distribution network. Relatedly, the Association repeated their claim that distributed generation and rooftop solar were technologies adopted by the wealthy, since an average solar system at the time cost approximately 6,500 USD. Therefore, exemption from the transmission fee represented a "perverse subsidy" that was being paid for by distribution companies, and that had little benefit for low-income consumers (ABRADEE, Interview, March 20, 2017). This argument was also made separately by Light, the concessionaire of Rio de Janeiro and the second largest utility in Brazil. The distribution company cautioned that it would likely increase electricity rates for consumers who did not own distributed generation systems, a practice known as "cost-shifting."

The final revision of Resolution 482 was regarded by stakeholders who defended the changes as a forward-looking piece of regulation on the part of Aneel. Under the new rules, limits on the installed capacity of units increased from 1 MW to 5 MW. Utility companies were also obligated to connect generating units within 49 days. Aneel expedited the application process for interconnection to the grid by reducing the deadline for the concessionaire to issue its interconnection report (Figueiredo et al., 2012). Furthermore, to the chagrin of distribution companies, their proposal to charge a connection fee for owners of distributed generation systems was rejected. Aneel augmented tax benefits for solar power deployment, increasing the existing discounts in transmission and distribution system usage charges for owners of distributed generation systems to a 100% exemption. Overall, the revised interconnection rules were much more favorable for owners of distributed generation systems than for the regulated utilities. These regulatory enhancements came into force in March 2016. Table 4 summarizes the changes to distributed generation regulations, which resulted in Normative Resolution 687.

Table 4

Primary Changes to Distributed Generation Regulations under No. Res. 687

Classification	Year Revised	Size (kW)	Expiration of Credits	Maximum Time to Process Requests	Eligible Building Types
Normative Resolution 482	2012	0-100	36 months	82 days	Residential Commercial
Normative Resolution 687	2015	0-5000	60 months	24 days	Residential Commercial Condominiums and Multi-family Housing Remote Locations

Besides largely siding with owners of distributed generation systems on the issues of installation, allowable capacity, and transmission pricing, the new rules further allowed solar energy systems to be used beyond traditional rooftop generation. Consumers could now generate electricity through different configurations, including virtual net-metering, aggregated net-metering, and community sharing. Virtual net-metering allows energy to be generated at one of the system owner's properties, but the credits generated can be used towards other electricity bills as long as the utility company is the same in both locations. In particular, for residential consumers, aggregated net-metering allows condominiums and apartment buildings to install a generating unit and distribute the credits among the units. This regulatory change takes into consideration Brazilian cities where higher portions of the housing stock in densely populated areas and urban centers such as São Paulo and Rio de Janeiro are comprised of condominiums.

In theory, these changes would broaden the market by extending regulations to different building types and consumer profiles.

In the case of revising net-metering regulations, the regulator had translated its broad legislative mandate into an operational agenda, which was then implemented through a set of procedural requirements. For example, ABRADEE criticized the approach of Aneel on the basis that distributed generation had been framed during the regulatory process as a public benefit. Since distribution companies were only one segment of stakeholders, they argued that Aneel should more equitably distribute the costs of its regulatory policy. In justifying its decisions in the face of utilities' criticisms, Aneel asserted that a different regulatory design would infringe on the "non-discriminatory treatment to all users of the transmission and distribution systems" (J. Coelho, 2015). Moreover, Aneel referenced the same resolution to affirm its authority to support solar energy (Aneel, 1999). The agency had to defend how these new rules and regulations would benefit energy consumers in lieu of clear guidelines and regulatory precedent for inserting the new technology into the electricity system. The energy regulator has been both reactive and proactive: Aneel has crafted the regulations that govern distributed generation from the extensive process of consultation and responding to industry concerns, while exercising a more robust interpretation of its mandate.

The regulatory agency created a defensible set of procedures that provided an enabling framework for distributed generation. In recounting a conversation with a director of Aneel following the passage of the new rules, an ABRADEE representative explained the agency's insistence to use the interconnection rules as a "subsidy" to incentivize small-scale systems (ABRADEE, Interview, March 20, 2017):

> During a frank conversation with a director, he basically said, ‘We understand your point…but this is the time to accelerate.’ Because, they argued the following: ‘You see that from 2012 until the end of 2015, there were only a thousand consumer units.’ So, it’s necessary to use the regulations to see if something comes from it, to accelerate the process.

The directors of Aneel hoped that the new rules would “open the tap,” and that early adopters would aid in developing a commercial market for distributed generation and reduce the costs of PV solar installations. Granting a subsidy to connect their system to the grid was, in part, a gesture to compensate systems owners who were paying a higher price to overcome the learning effects for the new technology. Aneel’s directors even overruled the superintendent in charge of regulations and distribution on the issue of imposing a connection fee. The next tariff revision would occur in 2019 and they wanted to signal to utilities that they would consider their proposals to adjust for the social costs of distributed generation at that time.

Following the approval of Resolution 687, the Ministry of Mines and Energy entered with its own program to provide incentives for distributed generation. The Program for the Development of Distributed Generation of Electric Energy (ProGD) was launched in December 2015 with the official purpose to provide a legal basis for distributed generation.[39] The program also aims to stimulate the use of distributed generation based on renewable energy sources with a particular emphasis on solar photovoltaics. The MME announced a large budget of up to $25.6 billion USD in investments to support distributed generation systems until 2030 (MME, 2015). Under the program, the government plans to create and apply lines of credit for the installation of distributed renewable technologies. By early 2018, however, there had been no public announcements about what the ProGD program has actually achieved.

[39] These include ministerial decrees No. 538/2015, No. 13/2016, and No. 175/2016.

Some observers criticize the program for being pro-business and not intended to benefit the average consumer that owns a distributed generation system, since the ProGD program includes large-scale generation systems of up to 30MW (Costa, 2015). An interviewee from Aneel suggested that that the ProGD program is an example of how the MME sometimes creates policies that were first instigated by regulators. Oftentimes, these policies are more about creating a legal precedent to accompany an emerging policy issue, rather than intruding on Aneel's day-to-day activities. Referring to the ProGD program (Aneel, Interview Sept. 14, 2017):

> There was some movement, some stuff happened, but the agency is much more agile and all of our regulations pass through public consultation, public meetings, we interact more with consumers, with businesses. So, we have a better feeling of what's going on…We have more contact, so we know what's working, what's not working, and we act.

According to the interviewee from Aneel, the ProGD program does not interfere with its management of distributed generation regulations. The ProGD program was viewed as being moderately helpful in that it was a move taken by the Ministry to reduce certain legal barriers to distributed generation, but it ultimately did not reduce Aneel's discretion to shape net-metering regulations (Aneel, Interview, March 20, 2017).

5.3.3. Regulating Technological Change (2016-present)

Since the revision of the net-metering framework in 2015, Brazil has reached approximately 194 MW of distributed solar PV micro-generation and mini-generation deployment (see Table 5). The Ministry of Mines and Energy also released its long-awaited 10-Year Energy Expansion Plan proposition which projected that the country could reach more than 13GW of solar PV deployment by 2026 (Kenning, 2017). In accompanying these market changes, Aneel declared that it would review the net-metering policy again in 2019. The energy regulator expects that, by this time, distributed generation systems will have reached approximately 500 MW of installed capacity. Table 5 shows that, as of March 2018, the 22,737 distributed generation systems represent 267.45 MW of installed capacity. Figures 7 and 8 present Aneel's projections on the growth distributed generation.

Table 5

Installed Capacity and Total Number of Distributed Generation Systems by Source (kW)

Technology	Number of Systems	Installed Capacity (kW)	% of Total Capacity
Solar PV	22,564	193,706.42	72.43%
Small Hydro	38	39,190.70	14.65%
Biomass and Biogas	81	20,642.94	7.72%
Wind	53	10,285.60	3.85%
Natural Gas	1	3,627.68	1.36%
Total	22,737	267,453.34	100%

Note. Adapted from Aneel (2018a).

While solar energy advocates would like to see the industry grow more quickly, Aneel approaches this steady development as an opportunity to reformulate its regulatory strategy (Aneel, Interview Sept. 14, 2017):

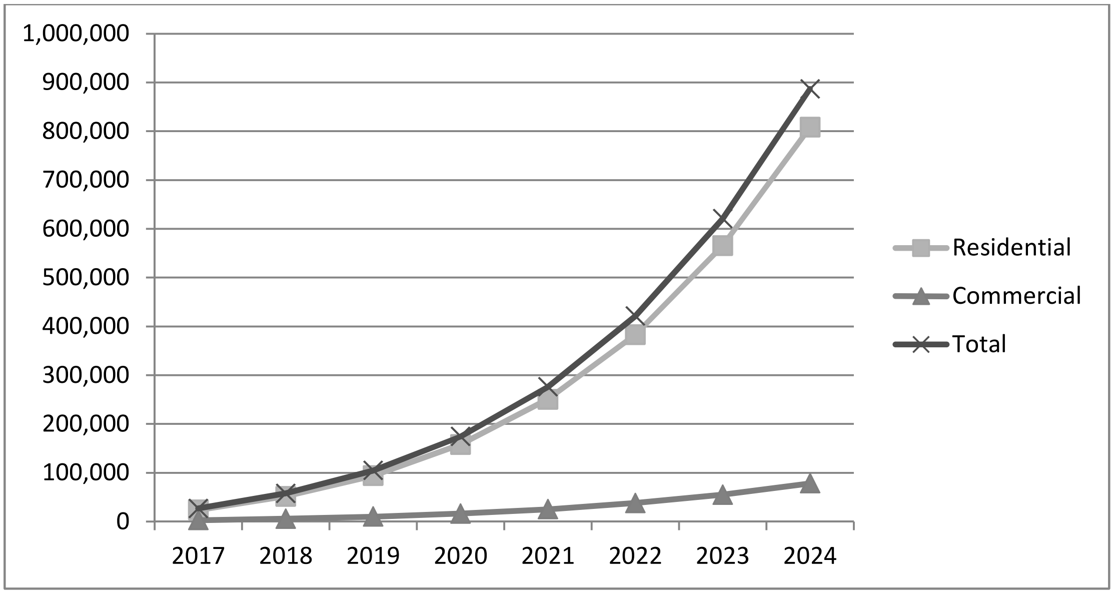
> Distribution companies think that we are going too fast, and equipment manufacturers think that we are going too slow. Aneel believes that we are going in the right direction, and we would be wrong if both parties were completely happy. We like to say here that they have to be equally dissatisfied, nobody can be completely satisfied, but you can't have someone that is much more dissatisfied than the other. If they're equally dissatisfied then we're doing our job.

From the regulator's perspective, the main objective is to closely accompany developments in the market to devise procedures that fairly allocate the costs and benefits of technological change. If the rate of diffusion falls short of their projections, regulators claim, they intend to be more proactive in providing favorable conditions. On the other hand, if distributed generation systems are adopted at a rate that exceeds their expectations, they will be less willing to maintain current subsidies. A third scenario also exists which, in the opinion of Aneel, is the most ideal. If the diffusion rate is well-aligned with regulators' projections, and the cost of the technology has dropped from increased experience and learning, they will revise the electricity tariff and increase the surcharge to connect to the distribution grid, the most salient point of contention for distribution companies. This is the scenario that Aneel has officially presented to the industry so that they can plan their operations, but with the qualification that the regulator can alter its course of action if distributed generation developments play out differently in practice (Aneel, Interview Sept. 14, 2017).

The lead-up to the next regulatory revision provides Aneel and other public authorities in the electricity sector with the time to analyze how distributed generation impacts the grid. The value in waiting to revise regulations lies in being able to consider other aspects of the existing regulatory regime. For instance, the issue of intermittency has become a central issue in the electricity sector. The grid operator, the ONS, has increasingly had to plan for the fluctuating supplies of electricity from large-scale wind and solar plants. While Aneel continues to study the effect of intermittency on the electricity system, it claims that the present number of distributed generation connections does not create many stability issues for voltage and frequency. Yet, the agency is already anticipating the challenge: "We're all going to learn together...In the future we're going to have to contribute to the response - regulation is dynamic, it accompanies the process, we don't have any problems yet but we're already planning on it" (Aneel, Interview Sept. 14, 2017). Aneel claims that, like much of its regulatory activities, it is responsive to changes as they occur. This interim period of revising distributed generation regulations allows it

Figure 7

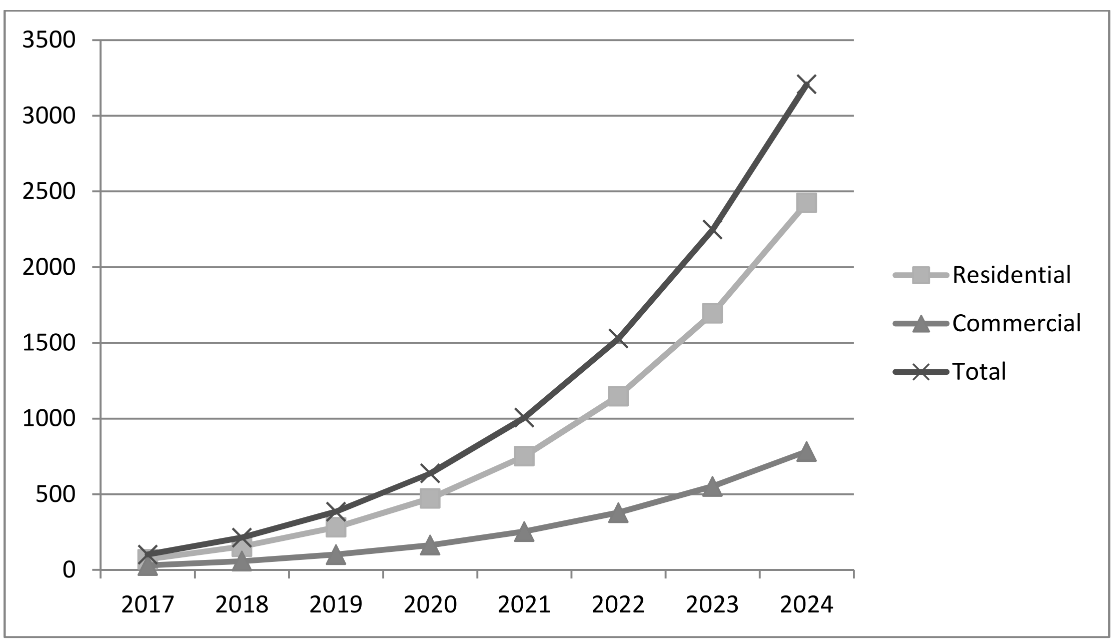
Projected Number of Net-metering Customers (2017-2024)



Note. Adapted from Aneel (2017).

Figure 8

Projected Amount of Installed Capacity (MW) from Distributed Generation (2017-2024)



to examine how distributed generation can be made more compatible with the electricity system, which has become a concern for all public agencies as they keep up with technological change in the energy sector.

Utilities incumbents have become alarmed by the growth of distributed generation and have mobilized to slow it down. Utilities are anxious about the next revision of net-metering, claiming that 2019 is too late to evaluate the policy. They believe it would be better to review the current tariff system now and that consumers pay charges separately for their energy consumption and their grid usage. More importantly, utilities are concerned about the growing coalition behind distributed generation and solar energy. According to a representative of ABRADEE (Interview, March 20, 2017):

> We are worried, that following [the changes] the lobby is going to get really strong, because the regulatory sessions and Aneel's decisions are carried out in a public way and transmitted on the internet. If I'm not wrong, [distributed generation] was the discussion item with the largest number of oral contributions from stakeholders, and so we were there, the distributors, and I was there making this defense, exactly what I have told you…and afterwards you have 16 people, entities, speaking in favor of not charging the connection fee…So, you have to be very careful."

Aneel's policy for involving stakeholders in regulatory deliberations strengthens interest groups and brings new organizations into existence. The regulatory process has thus had a vital role in constituting the associational order behind distributed generation (Ayres & Braithwaite, 1992, p.14). In addition to solar manufacturers and suppliers, there has been a proliferation of renewable energy and distributed generation associations, such as the Brazilian Association of Distributed Generation (ABGD), founded in 2015, and the Brazilian Association for Solar Thermic Energy (ABRASOL), founded in 2016. With a growing lobby behind distributed generation, utilities are afraid that consumers and advocacy groups will increasingly defend favorable connection rates as a “right” instead of as a short-term subsidy. The broad coalition of consumer groups, solar energy installers, environmental organizations, and trade associations also means that utilities companies are outnumbered in public hearings.

While many regulated utilities attempt to actively block the take-off of distributed generation, other companies are becoming leading investors in the area. CPFL Energia, Brazil’s third largest utilities company, has entered the solar distributed generation segment under a unregulated subsidiary, Envo. CPFL has already begun working on distributed generation projects, including a microgeneration research project in São Paulo state, through which it can evaluate the local residential market. CPFL recognizes the distributed generation receives from various incentives, including tax exemptions, making it a profitable business. The fact that such large energy groups often own commercial subsidiaries that do not act in the regulated market gives them an opportunity to view distributed solar generation as an attractive investment (Aneel, Interview, Sept. 19, 2017). Rather than a united front of utilities that lobby against distributed generation, some utilities companies accept the idea that they need to incorporate renewable energy and small-scale generation technologies in order to stay competitive.

Despite having to deal with incumbent utilities that are resistant to change, Aneel has largely approached their criticisms as an opportunity to learn how to improve regulatory design (Braithwaite, 2011). Like the solar and wind lobbies, ABRADEE interacts directly with Aneel in the regulatory arena to provide technical support and advocate for projects that affect electricity concessionaires (Interviewee, ABRADEE). The relationship between Brazilian utilities and regulators is marked by conflict but can also be collaborative. One interviewee from Aneel compared the new distributed generation regulations to the app-based, car-hailing service Uber, in that they represent a change in paradigm (Aneel, Interview, March 20, 2017). Since distributed generation have already set in motion a change in the traditional utilities model, as a regulator, you need to learn how the new system functions in order to know how different elements in the system can co-exist.

For example, regulators agree that the current net-metering scheme does not adequately internalize all of the social costs and externalities of distributed generation, nor does it properly compensate utilities companies for maintaining the distribution and transmission network. ABRADEE has proposed several ways to restructure the compensation system for net-metering, such as using funds from the Energy Development Funds (CDE), the public benefit fund which is used to promote social considerations in the electricity industry (ABRADEE, Interview, March 20, 2017). While CDE funds cannot legally subsidize the costs of distributed generation, regulators are open to adopting a revised incentive structure that incorporates utilities companies' suggestions (Aneel, Interview, March 20, 2017; da Silva, 2017).

In addition to altering the regulatory framework, the agency has acted in secondary ways to facilitate the expansion of distributed generation. These revisions in the framework were coupled with R&D programs that began in 2012 and benefited domestic solar energy. Aneel has utilized its discretion in overseeing the qualification standards for energy efficiency and R&D programs as an opportunity to steer domestic developments in solar energy. In conjunction with the revision of Resolution 482, since late 2015 Aneel has launched several public calls for projects focused on solar energy, such as photovoltaic systems, general research, and improvements in energy efficiency using solar energy (Aneel, 2015). This has created added supports to increase regulatory credibility, demonstrating a clear and concerted effort on the part of Aneel to promote small-scale solar energy (Greenpeace, Interview, July 5, 2016).

5.4. Conclusion

The inner world of the regulatory process has implications for understanding the diffusion of wind and small-scale solar technologies. As the administrative patrons of renewable energy programs, regulators have some discretion to reinterpret what a policy means and how they choose to act (Yarrow, 1996). In other words, regulators can insert their own values in policy formation and shape the character of renewable technologies in terms they consider best. For wind energy, Aneel's oversight of the transmission planning processes and the de-contracting auction are two cases in which the regulatory agency ensured the long-term expansion of wind energy. In both situations, Aneel formed a collaborative partnership with the Ministry of Mines and Energy and key stakeholders to overcome regulatory challenges. However, since project developers frequently delay or abandon auction projects, enforcement has ensured the effectiveness of the auction process. While studies on improving auction implementation devote attention to design choices that can mitigate the non-delivery of projects, Aneel's rigid approach to enforcing contractual obligations has improved the implementation of projects and, in turn, enhanced its own legitimacy within the electricity sector.

Similarly, the absence of political interest in distributed generation has allowed regulators to steer the diffusion process. Since the transition to more small-scale generation technologies fundamentally questions the institutional arrangements and organizational stability of the electricity system, Aneel has used the iterative nature of the implementation process to gradually adapt regulations to this emerging technology. Electric utilities have strongly contested these changes, and Aneel has used the regulatory process to align its organizational interests with external groups and establish a supportive technological coalition. Similar to resolving regulatory problems with wind energy, the agency uses public consultation to collaborate with stakeholders and gather information relevant to its decision-making. Public consultation also increases confidence in the regulatory process by allowing affected stakeholders to openly contribute to or contest the agency's decision-making and provide clarity about regulators' intentions.

Chapter 6

The Role of State Governments in Energy Transitions

In previous chapters, I demonstrated the Brazilian government's willingness to diversify the electricity supply with wind and solar energy. Against the backdrop of an electricity system shaped by large-scale hydroelectric power, the energy regulatory agency, Aneel, has devised regulatory strategies that promote non-hydro technologies. While regulations are often construed as barriers to technological change, Aneel has been a protagonist in building regulatory frameworks that ensure the development of wind and solar technologies.

By employing a geographical lens, the aim of this chapter is to examine under what conditions states and regions engage in the development of wind and solar markets. The three states of Pernambuco, São Paulo, and Rio Grande do Norte were selected as comparative case studies. The chapter begins by summarizing the administrative changes that have placed states in a more decentralized pattern of decision-making and energy planning. For each case, I systematically outline the state-level planning context and implementation processes that have facilitated or precluded policy developments in wind and solar. I then show how local actors and institutions interact in and coordinate policy processes. The main conclusion is that there is wide subnational variation in terms of how states develop policies that respond to their local energy and economic priorities. Consequently, while natural resource potential is important, it should be understood in terms of the context in which renewable technologies are developed and deployed.

6.1. Decentralization and State-level Energy Planning

State-level engagement with renewable energy governance has occurred within broader national shifts that have increased regional responsibilities for national policy and planning. The military dictatorship had limited the importance of federalism in Brazilian politics by constraining subnational governments' political and fiscal autonomy (Samuels & Abrucio, 2000). During the 1990s, the movement towards less government involvement in the economy had several implications for states. Many states had accumulated high debts, stemming from the use of state-level banks as loan agents. A national law consequently required that subnational governments control their public expenditures and indebtedness.[40] While a focus on fiscal accountability initially limited state activities, the outcome of these measures was a reshaping of Brazilian federalism. States and municipalities were granted their own financial resources and administrative authority. In particular, subnational governments were to use tax resources and discretionary transfers to implement public policies (Soares & Neiva Pereira, 2011).

In terms of fiscal policy, taxes are an important source of state revenue and tax exemptions can be used to attract energy-related businesses and investments. The development of local energy resources can present long-term economic development opportunities for a state, such as job creation and oil and gas royalties. Currently, a significant number of states have acted through the Brazilian tax code to exempt renewable energy generators from the ICMS (Merchandise and Services Circulation Tax), a state government value-added tax. The original imposition of the ICMS tax was blamed for the slow adoption of solar installations. São Paulo and Pernambuco were among the first states to provide this exemption. In 2015, the Brazilian Council for Financial Policy (CONFAZ), a department of the Ministry of Finance, approved the

[40] The Fiscal Responsibility Law (LRF) in 2000 has become the cornerstone of this adjustment process.

exemption of ICMS for all states. However, states can still choose to opt out of exempting the tax.

The decentralization of administrative responsibilities has still required provincial planning authorities to operate under national guidelines. In the case of constructing power facilities, energy businesses need formal and informal local consent for their developments (e.g. planning permits) (Smith, 2007). An Environmental Impact Assessment (EIA) is required to address the potential social and environmental impacts of large energy projects. Many aspects of the environmental licensing process are decentralized to state and municipal governments. In 2011, the Ministry of the Environment (MMA) drafted special regulations to standardize the licensing of wind farms. State governments are thus obligated to align their institutional understandings with federal provisions (Hochstetler, 2011).

In addition, advocates of renewable energy can form partnerships with local actors and institutions to coordinate the diffusion of alternative energy technologies. Universities use their capacities in research and educational training to support technological advances and regional economic development. In this regard, universities in the Northeast have been experimenting with the development of wind and solar technologies since the 1980s, unlike universities in the Southeast which have focused on R&D for hydro and sugarcane biomass. Given their role in regional development policy, Northeastern universities have a strong incentive to build on these existing capacities when more resources and legitimacy are given to wind and solar. Wind manufacturers in particular have an interest in locating their production facilities nearest to wind energy markets, given the cost and infrastructural demands to transport large wind turbines and towers to site locations.

Finally, existing energy infrastructures can exert significant influence over how states develop and use energy. While regional energy transitions depend on the availability of sufficient resources for energy generation, infrastructures influence how energy sources can be exploited. For instance, large investments in the national electricity grid were intended to build out the country's hydroelectric potential. Consequently, transmission planning focused on erecting an expansive, country-wide interconnection to enable the exchange of energy between regions, theoretically allowing the electricity system to draw on several river regimes and basins. This type of system, however, did not anticipate technological change and significant increases in non-hydro sources of energy. States which lacked the potential to generate hydroelectricity were often conceived as energy "recipients," even though they possessed favorable wind and solar resources. In sum, the transmission infrastructure can be an important factor in mediating the use of physical resources and regional energy governance.

The following state-level case studies highlight how different political, economic, and natural resource contexts influence how states frame their strategies in developing wind and solar resources. Since the first energy auctions in 2009, policy entrepreneurs in Pernambuco and Rio Grande do Norte have tested the potential of wind and solar when such energy sources were viewed as marginal by the national government. In São Paulo, similar initiatives have been eclipsed by the state's drive to exploit offshore oil reserves and support the regional sugarcane industry. While not an instance of a "successful" case, state-level activities in São Paulo underline how well-established advantages in natural resources and regional priorities influence policymaker's decision-making and the development of particular energy paths.

Figure 9

Map of Brazil with Case Study States

6.2. Pernambuco

The state of Pernambuco is located in the Brazilian Northeast, a poor region susceptible to periods of severe droughts. During the 1990s, with the movement toward privatization and less public sector involvement in the economy, the federal government began to withdraw its support of programs to support poverty alleviation, agriculture, and employment in the Northeast. Pernambuco and neighboring states had to seek new approaches to economic development based on establishing competitive advantages (Feferman, 2014). South of the Pernambucan capital of Recife, the Port of Suape is an industrial complex and an important logistical center. To foster a local petrochemical industry, the Abreu and Lima Petrobras refinery was constructed near the port in 2013 which has been hailed as the most modern and technically advanced refinery constructed in the country. Pernambuco produces approximately 70% of its electricity from diesel oil and natural gas, and has a moderate amount of installed capacity in wind and solar energy.

The Governor's Office and the Economic Development Secretariat (Sdec) are responsible for guiding energy policies and priorities in Pernambuco. Sdec, the state's economic development agency, promotes industrial and commercial development by forming public-private partnerships (Sdec, 2017). Previously, state electricity supply planning had prioritized building more fossil fuel-powered thermoelectric plants and potentially a nuclear plant. Recent governors have supported renewable energy projects, especially solar energy. Viewing hydro and wind as relatively mature technologies, one former Pernambucan governor, Eduardo Campos (2007-2014), was cited by several interviewees as having been a vocal supporter of a local solar industry which would create regional growth and a local manufacturing industry for renewable technologies (Sdec, Interviewe, July 12, 2017; Semas, July 13, 2017). The current governor has continued political support by viewing renewable energy as part of a comprehensive plan to exploit the local economic benefits of energy projects.

In devising energy policy for Pernambuco, the Executive Secretary of Energy, a division within Sdec, proclaimed its objective to consolidate the state as a generator of clean energy and productive pole for equipment, technology, and knowledge in the sector (Abinee, 2015). In collaboration with the Energy Secretary, the Pernambuco State Secretary of Environment and Sustainability (SEMAS) formulates and carries out environmental policies for the state government (SEMAS, 2017). SEMAS representatives have stated that their priority is to create a vision and strategies to transition to a low-carbon economy, an agenda that gained momentum following the Earth Summit 2012 on sustainable development held in Rio de Janeiro (Semas, July 13, 2017). With its strong focus on decarbonization, SEMAS oftentimes partners with the Energy Secretary on renewable energy projects.

6.2.1. The implementation process in Pernambuco

The initial efforts to incentivize solar energy within the state emerged as a partnership between the state government and the Energy Secretary at Sdec. Around 2012, then Executive Energy Secretary, Eduardo Azevedo (2010-2016), observed that Pernambuco had the potential to develop solar energy that was not being recognized at the federal level. Despite Brazil's high levels of solar radiation, public policies for stimulating renewable energy sources, such as Proinfa, did not include solar energy. Compounding this issue was the Energy Planning Enterprise's low estimates of annual added capacity for utilities-scale solar, which were insufficient to attract investors to build up the solar supply chain. For technology suppliers, the national auction system provides a pipeline of planned and approved projects on which they base their future operations. To feel secure about their investments, manufacturers were calling for a guaranteed 1 GW of solar to be contracted per year for the next ten years. This departed from national planning targets to contract 3.5 GW within four years (MME, Interview, March 21, 2017). In general, federal policymakers had low expectations for solar energy as a viable supply technology.

State energy planners observed that they could provide guarantees for solar developers and manufactures that were not being adequately signaled by national-level plans. Policy supports, such as a state solar auction, could produce lower prices than what was being stated in official government figures. In December 2012, the EPE published a study which estimated that the average cost for solar energy in Brazil was around $US201 per MWh. According to the Energy Secretary, this price seemed unusually high, so he decided to conduct his own study. The calculations provided by the energy division at Sdec revealed that the price for solar was actually in the order of $US124 per MWh. With these new estimates in hand, he approached the state governor to convince him that solar energy could present opportunities for regional economic development. After initial conversations, the governor took on an important facilitating role in "opening doors" to support solar energy in the state (MME, Interview, March 21, 2017).

In December 2013, the first state-led auction in Pernambuco resulted in several successful policy lessons regarding the price and performance of the nascent solar market. The auction contracted the largest amount of solar energy in the country at the time, awarding six successful tenders which accounted for nearly 123 MW of solar projects. The resulting price, which was lower than the federal government's estimates, contradicted the predominant view that solar power could not compete with conventional forms of power generation. This new price signal convinced federal policymakers to hold a reserve auction that included solar energy in 2014. Other states also considered local auctions as way to attract investments in renewable energy (Neves, 2015), although no new state-level auctions have been held. [41] The state solar auction in Pernambuco thus broke much of the political inertia and thinking surrounding the potential of utilities-scale solar.

The experience gained from resolving the procedural issues which followed the first state auction encouraged energy policymakers to plan for large-scale solar energy. To manage the negotiation of energy contracts, the government of Pernambuco created its own power trading company, the Pernambuco State Economic Development Agency (AD Diper), linked to the State Secretariat of Economic Development (Sdec) and the national Electric Power Trade Board (CCEE).[42] The purpose of the agency is to mediate between the purchase and sale of energy in state solar auctions under Brazil's unregulated market rules, which permit consumers to buy power directly from generators or traders through bilateral contracts. To absorb any excess electricity, public agencies in Pernambuco have been encouraged to migrate to the free market system managed by AD Diper. Public authorities and buildings are often large consumers of electricity through the operation of hospitals, schools, offices, and street lighting, and can stimulate demand for electricity generated from renewable energy sources. For example, the Convention Center of Pernambuco was the first to switch to the new system and receives electricity directly from the hybrid Tacaratu wind-solar plant. Sdec has begun to map 100 of the most energy-intensive buildings in the state, which it eventually hopes to bring into the free market for locally-produced renewable energy (MME, Interview, March 21, 2017; Sdec, Interview, July 13, 2017).

[41] The state of Minas Gerais planned to hold a solar energy auction at the end of 2016. The states of São Paulo and Piaui have also expressed interest in hosting renewables-only auction, but have yet to taken any action.

[42] Following the example set by Pernambuco, the state of Parana created a power commercializer. However, it was eventually absorbed by Copel, the state distribution company.

Pernambuco also focuses on helping regional and international firms and businesses enter renewable energy supply chains to attract inward investment. According to one interviewee, the majority of businesses that decide to move to Brazil seek out state representatives to weigh the advantages and disadvantages of locating their operations in one state over another (MME, Interview, March 21, 2017). For instance, companies ask why they should go to Pernambuco rather than São Paulo and Rio de Janeiro, which are more widely known outside of Brazil as industrial and financial hubs. A part of the state's entrepreneurial activities is leveraging the Port of Suape as an attractive hub for wind and solar manufacturing businesses. The Port of Suape has the advantage of geographical proximity to the Recife metropolitan region and is well-connected by interstate highways that allow manufactures to transport equipment to the main areas of high wind generation potential in the Northeast.

The use of market-oriented policies for renewable electricity feeds into broader strategies for regional economic development. As an extra form of public support, the power trading company, AD Diper, buys electricity directly from wind, solar, biomass, and biogas plants and resells electricity at a competitive price for companies seeking to relocate to Pernambuco. The offer to provide cheaper prices for electricity and discounts on the ICMS tax is another attraction for companies, especially energy-intensive industries. These companies are also motivated to purchase renewable energy to improve their socio-environmental indicators and performance benchmarks for their stocks, many of which are publically traded on the New York and London stock exchanges (Sdec, Interview, July 13, 2017). The fact that AD Diper is part of Sdec has helped the agency incorporate economic development opportunities into regional energy policies.

Finally, the state has created policies to overcome barriers to the local uptake of solar distributed generation systems. The national regulatory framework for distributed generation had initially resulted in a smaller number of installations than regulators had predicted. To encourage the use of small-scale PV solar systems, the Government of Pernambuco partnered with state agencies and government-owned development banks to create the PE Solar Program. The aim of the program is to provide local financing for residential consumers and business. Banco do Nordeste, a regional development bank responsible for economic development in the Brazilian Northeast, provided the initial resources for the program. With a grace period until the distributed generation system is running, the eight-year loans have competitive interest rates of 4.5% to 7% – very low compared to interest rates for commercial loans of more than 50% a year. This program has generated learning about how to improve the payback period on small-scale solar PV systems.

6.2.2. Supporting regional actors and institutions

The competences of existing local economic and technological organizations have been further mobilized to build up the state renewable energy industry. The State Development Agency of Pernambuco (Agefepe) provides credit for small enterprises, cooperatives, and rural producers, and was given the task of administrating the project financing for the PE Solar Program. These programs are supported by the Secretariat of Small and Micro Enterprises, Work, and Qualification (SEMPETQ) which provides workforce training, and manages a professional network of solar energy installers and other solar-related services.

At the scientific and technological level, several universities and research institutions have historically carried out R&D activities and installed local demonstration projects for renewable energy technologies. The Federal University of Pernambuco (UFPE) has pioneered studies in photovoltaic technology since the 1980s and in wind energy since the early 1990s. The Brazilian Center for Wind Energy (CBEE) has worked independently as well as formed partnerships with the federal government to launch demonstration projects to test sensors and other instruments. The wind and solar energy industry are closely connected to Pernambuco's universities. For example, the previous head of the Brazilian Center for Wind Energy, Everaldo Feitoso, left the Federal University system to create the largest investment company in wind and solar energy in Pernambuco, Eólica Tecnologia.

Furthermore, in partnership with local distribution companies, Pernambuco has developed prominent demonstration projects for solar and wind energy. Notably, Fernando de Noronha, an archipelago of 21 islands off the coast of Pernambuco, is used by policymakers, researchers, and firms to learn about how to adapt new energy technologies to the islands' unique characteristics. According to a representative of the State Environmental and Sustainability Secretary who works on developing projects in Fernando de Noronha (Interview, June 13, 2017):

> The Fernando de Noronha archipelago, which is where we are creating these projects, is really a concrete action plan. We have a partnership with the state government of California and the American Consulate so that we can better develop a low-carbon economy and transition process…Since it's an isolated territory, this makes it possible to validate technologies along the line of sustainability and, when proven successful, these products, services, we can migrate them quickly to the continent. The island also is widely visible not only in Brazil, but globally, and can serve as a point of reference.

Since the archipelago generates most of its electricity from diesel fuel, it presents an interesting site to test renewable technologies while improving local energy security. The first operational wind turbine in the country was installed on the island in June 1992 by the Wind Energy Group at UFPE, in conjunction with the Pernambuco Electric Company (CELPE) and Folkecenter, a Danish research institute. Electricity generated from the turbine accounted for around 10% of the energy generated on the island, which saved approximately 70,000 liters of diesel per year. A second turbine was installed on the island in May 2000. Together, these projects have made Fernando de Noronha the home of the largest hybrid wind-diesel system in Brazil (Aneel, 2005). Since 2014, solar energy has come to supply about 4% of the island's consumption. The state government also intends to use wind and solar projects there to test energy storage technologies (Sdec, Interview, June 12, 2017). The state-owned generation company, The San Francisco Hydroelectric Company (Chesf), has also used R&D funds to build solar energy plants in sunny areas of the state's interior (Chesf, Interview, July 13, 2017).

6.2.3. Summary

While Pernambuco has developed an innovative public procurement system to stimulate renewable energy, the program has run into several procedural issues. Only one project from Enel Green Power, the hybrid wind-solar plants located in the municipality of Tacaratu, was ready to start generating electricity within the original timeframe. The state environmental licensing process had caused delays that were prolonged by the issuing of federal operating permits. Furthermore, following the national reserve auction hosted by Aneel in October 2014, the states of Bahia and Rio Grande do Norte have surpassed Pernambuco in terms of planned installed capacity for solar energy. This second generation of solar projects has benefitted from policy lessons and changes in the expectations for utilities-scale solar energy that were first initiated in Pernambuco. The state's initiatives prompted Aneel to introduce solar energy into future auctions and to design auction contracts that more strictly took into account access to transmission infrastructure to facilitate interconnection (Sdec, Interview, July 12, 2017). Distributed generation is an emerging technology which is also framed to address locally specific-problems. In Pernambuco, distributed generation takes on a more comprehensive role in Pernambuco's solar policy agenda compared to other states.

In summary, the state's energy planners have focused on testing and developing solar technologies at a time when federal policymakers had low expectations for it. Policy entrepreneurs have had considerable latitude in crafting a significant set of policies to foster a protective space for solar and wind energy. The current Secretary in charge of the Energy Division at Sdec, however, has expressed reluctance to provide subsidies for solar energy, viewing solar as still relatively immature and expensive (Sdec, Interview, July 12, 2017). Despite the decrease in enthusiasm for creating special supports for solar in the energy planning division, the view of the state government administration is that these policies have become part of a more comprehensive vision to develop renewable energy and industry. This is reflected in an interview with a former State Secretary of Economic Development (PE, 2015):

> We can combine three important movements. First, we help the small and medium business owner reduce their electricity bill. Second, we have increased the use of renewable energies in the State, strengthening Pernambuco as a pole of development in this area. If we can expand that base by using many photovoltaic power plants in the state, the next step is to start building an industry base in the state that can provide such equipment. Thirdly, we fulfill our role in helping to expand the country's energy matrix.

In Pernambuco, progressive solar energy policies eventually gained the support of other government agencies. Policy experiments conducted at the state-level have gradually evolved into shared expectations and practices for solar energy at the national level. The various demonstration projects in the Fernando de Noronha archipelago are held as a symbol of the state's commitment to renewable energy and a low-carbon economy. Local institutions, such as research groups at the University of Pernambuco and the local distribution company, Celpe, tested wind and solar technologies well before they were considered viable sources of electricity generation in Brazil. Their growing role in developing new renewable technologies has resulted, in part, from the state government's regional mandate to consolidate wind and solar into economic development.

6.3. Rio Grande do Norte

Rio Grande do Norte is in Brazil's Northeastern Region at the eastern tip of the South American continent. The state's geographical position and port infrastructure furnish it with an important position in terms of logistics for the wind industry in the Northeast. Rio Grande do Norte is the national leader in wind energy, representing approximately 32% of national installed capacity. Strong and stabilized trade winds, which blow in across the Atlantic from Africa, are responsible for the state's favorable wind resources. The 2014 reserve auction attracted solar energy for the first time to the state (Aneel, 2018).

Historically, Rio Grande do Norte has been an administrative center for the oil industry in the Northeast, being the third-largest state in Brazil in terms of oil production and the fifth for natural gas (MDIC, 2014). Located at Petrobras' industrial hub in the city of Guamaré, the Potiguar Clara Camarão Refinery produces diesel fuel, petrochemical naphtha, jet fuel and, automotive gasoline. While the state is a regional hub for oil extraction and processing, the state has relatively few thermoelectric plants that burn fossil fuels for electricity. Petrobras's Northeastern operations located its oil refining facilities in Pernambuco in 2013 for political reasons (IFRN, Interview, July 27, 2017). Petroleum extracted in the state travels roughly 500 kilometers southward to be refined in Pernambuco's Abreu e Lima oil refinery. This effectively diminished Rio Grande do Norte's capacity to generate electricity from its abundant oil deposits.

Strategic energy planning is carried out in partnership between the Secretary for Economic Development (SEDEC) and the Center for Strategies in Natural Resources and Energy (CERNE), a third-party organization and think tank based in the state capital, Natal. With the advent of Proinfa, the state government recognized the potential of wind power for regional economic development. In addition to being more labor-intensive than fossil fuel power generation, wind power could create jobs in wind park operation and construction as well as attract outside investors. SEDEC's purpose is to facilitate the implementation process by ensuring a favorable investment environment. CERNE, managed by a staff with technical experience in the energy sector, mediates between private energy companies and the state government while providing market research on the Northeastern market (CERNE, Interview, July 20, 2017).

6.3.1. The implementation process in Rio Grande do Norte

The development of the state wind industry emerged in the context of a regional reliance on electricity imports. According to Aneel, until 2003, no power plants had been installed in Rio Grande do Norte and the state generated no electricity. The state was essentially a net energy importer located at the Northern tip of the national transmission system. A milestone for the state's supply planning was the first operating wind farm inaugurated in the municipality of Macau in 2003. The electricity produced is transported through underground cables to power two oil platforms owned by Petrobras. Petrobras was thus an early actor in experimenting with wind energy for large-scale generation in the state.

The history of wind power in Brazil is directly related to Rio Grande do Norte.[43] In the early 2000s, the state began to create policies and regulations to introduce wind energy as an alternative form of centralized generation of electricity. Several interviewees cited Jean-Paul Prates as instrumental to shaping the nascent wind industry in the state. A former Petrobras

[43] Ceará and Rio Grande do Sul are also considered "vanguard" states in wind power, constructing wind farms before the creation of a national auction system. For information on wind development in Ceará, see Gorayeb and Brannstrom (2016).

engineer and founder of an energy consulting company, Prates acquired the sobriquet "the lone wolf" of the Brazilian wind industry (Sciaudone, 2010; CERNE, Interview, June 22, 2017). He observed that the state, which had no power plants, lacked the planning which could develop the state's untapped wind resources. As an early believer in the development benefits of a regional wind sector, the governess of Rio Grande do Norte at the time, Wilma de Faria (2003-2010), created a Secretary of Energy especially for Prates to administrate the state's energy-related issues. In 2010, a statewide budget cut eliminated the Secretary of Energy. To fill the void of a state-level representative to articulate the needs of the growing wind industry, CERNE, led by Prates, was created as a private entity to carry the role of a state energy division. This pattern of private sector leadership combined with state government backing has been characteristic of the wind energy sector in Brazil, and in Rio Grande do Norte.

While the strong wind energy potential in the Brazilian Northeast had long been recognized, federal policymakers and planners thought that wind was too expensive and would never compete financially with hydropower and biomass. As Secretary of Energy at the time, Prates, along with representatives from Pernambuco, Ceará, and Rio Grande do Sul state in the South, challenged the government to create a technology-specific auction for wind energy. States with well-endowed wind resources wanted to prove that wind energy was a technologically viable option for long-term supply planning (Eólica Tecnologia, Interview, July 17, 2017).

Furthermore, industrial interests in Rio Grande do Norte have drawn attention to the state's willingness to consolidate a local manufacturing and industrial pole for wind energy. For turbine and wind equipment suppliers, regular auctions provide investment stability by providing a guaranteed pipeline of planned and approved wind projects. In addition to its high and reliable wind currents, the state is located in a strategic position between Ceará, Pernambuco, and

Paraiba, states that are also active in developing their wind energy potentials. In forming a coalition with CERNE, The Federation of Industries of Rio Grande do Norte (Fiern), which supports industrial and commercial development in the state, worked with neighboring states to attract wind industry manufacturers to supply the growing industry. Notably, before creating state solar polices at the Energy Secretary in Pernambuco, Sergio Azevedo presided over the Committee for Renewable Energy at Fiern. Until 2011, he worked alongside Jean-Paul Prates to expand the state's incipient wind industry and attract international investors (MME, Interview, March 20, 2017).

The realization of wind power potential also depends on the development of better infrastructure to move electricity from its point of generation in wind turbines to the point of consumer demand. While Rio Grande do Norte is the state with the greatest potential for wind power in terms of average wind speeds, the ability to export wind-generated electricity across state and regional lines is limited by the its unique position within the national transmission system. As previously mentioned, national energy planners conceived the state as a net importer of electricity, rather than an exporter, because its semi-arid climate prohibited it from developing hydropower. Consequently, the transmission and distribution networks did not extend to the areas where wind developers wanted to construct their projects. As another consequence, the Transmission System Use Tariff (TUST), comparable to a state "toll" paid by investors to transmit their electricity to the grid, made it more expensive for investors to generate electricity in Rio Grande do Norte. At the time, the state's TUST charge varied between 2.57 and 2.89 USD/MWh. In neighboring Ceará state, which also has wind energy potential, the tariff cost ranged from 1.59 to 1.90 USD/MWh (Moura, 2009). In sum, Rio Grande do Norte was impaired in exporting renewable wind energy because of assumptions embedded in the original transmission system.

The first "wind only" auction was organized by the Brazilian Ministry of Mines and Energy and Aneel in December 2009. To the surprise of the federal government, which had low expectation for wind energy, the final price was much lower than government estimates (Eólica Tecnologia, Interview, July 17, 2017). The auction's initial price was 59.90 USD/MWh; the final average price was 46.95 USD/MWh, 21% less than the initial price (Bezerra et al., 2010). Wind also underpriced natural gas-fired power projects, where the price was USD 65/MWh for natural gas. Furthermore, the majority of contracted wind projects would be built in Rio Grande do Norte, representing 657 MW of the 1,805.7 MW of contracted electricity. These favorable auction results contradicted the view that wind power could not be fully competitive, and that it would need subsidies or special auctions rules for its insertion in the energy supply. As a result, wind energy advocates and investors argued for fix a regular schedule to include wind in energy auctions.

Since wind energy secured a place in the auction system, the state government created conditions to facilitate the infrastructure planning and interconnection process and align Aneel's contractual requirements with anticipated in-state investments. While Ceará state had already developed a local wind supply industry, Fiern and CERNE collaborated on a report for the recently elected governess, Rosalba Ciarlini, highlighting Rio Grande do Norte's role in attracting businesses that could supply secondary products to the renewable energy industry, such as transformers and inverters. The partnership between Fiern and CERNE was an important impetus for developing the wind energy sector. It fell upon them to convince the new state government administration and legislature that wind could be a lucrative and viable industry

(CERNE, Interview, June 22, 2017. This union of industrial interests and energy investors was crucial to the beginning in securing a wider base of support for wind energy as well as sustaining political resources for CERNE in lieu of a state energy secretary.

The first two rounds of wind energy-specific auctions doubled installed capacity in the state from 50MW to more than 1GW. In a few short years, Rio Grande do Norte became a net exporter of energy, supplying electricity to other Northeastern states. In particular, 2011 represented a turning point for Rio Grande do Norte, where it became the largest state to generate electricity from wind energy. In that year, five wind parks were installed and began to operate commercially. Four more parks were installed in 2012 (Neto, 2015).

Furthermore, Rio Grande do Norte has been active in adapting environmental regulations and licensing procedures to the technical specifics of wind projects. Over time, the Institute for Economic Development and the Environment (IDEMA) and The National Institute for Historical and Artistic Patrimony (IPHAM), state agencies in charge of environmental licensing, collaborated to simplify the often time-consuming and complex environmental licensing process (Hochstetler, 2011). In 2011, IDEMA created a department dedicated to carrying out the environmental licensing of energy projects. The Institute's Wind Farms Division was carved out specifically to handle the rising influx of wind project licensing requests. The fact that the state has no hydroelectric plants and relatively few fossil fuel-powered thermoelectric plants has made it easier for the agency to focus on licensing wind projects and the few licensing requests for solar plants (IDEMA, Interview, July 21, 2017). Since wind energy has become critical to regional development, state governors have encouraged IDEMA to modernize its environmental licensing process to facilitate the development of wind projects (IDEMA, 2015).[44] Interviewees

[44] Interviewees from state environmental agencies asserted that the streamlining of environmental licensing procedures did not change the quality of wind projects. Critics of wind projects, however, argue that the wind

mentioned that they exchange environmental licensing practices with other states that have experienced significant growth in wind energy (IDEMA, Interview, July 21, 2017).

While environmental licensing is often characterized as bureaucratic and time-consuming, representatives from IDEMA claim to facilitate the development of wind projects. According to interviewees, when a date for an energy auction is scheduled, employees focus their efforts on giving early licensing approval (IDEMA, Interview, July 21, 2017):

> We put in a big effort [before auctions], we extend our work hours, to make sure that everything happens on time….We have a conversation with investors here beforehand, we schedule meetings, so that they are already familiar with the type of study and they have already begun the process, precisely to shorten the time it would take to grant a license.

These early interactions with investors ensure compliance with Aneel's auctions rules in which candidate projects have to demonstrate that they are able to connect to a nearby high-voltage transmission line or distribution network. A close relationship with state environmental agencies also confers more credibility to a project's viability, showing that it can be successfully implemented. An expedited environmental licensing process further supports the state's economic and political priorities. Since wind energy has become a critical industry in the state, IDEMA has been encouraged by the state governor, Robinson Faria (2015-present), to modernize its environmental licensing process to facilitate the development of energy projects (IDEMA, 2015). IDEMA's reflections on the environmental licensing process conform to preliminary interviews with representatives from the Secretary of Energy in Rio Grande do Sul state, who claimed to have attuned their administrative capacity to the state's energy investment environment (RS SME, Interview, Sept. 23, 2016).

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industry often minimizes the environmental and social impacts caused by wind farms, which can lead to conflicts between wind developers and local communities. See da Costa (2016).

At the national level, regional actors have lobbied to attract international investments in renewable energy. Like Pernambuco, Rio Grande do Norte has been proactive in capturing businesses to build up the regional wind and solar supply chains. The state governor's office has been eager to negotiate with international investors who have considered locating their businesses in the Northeast. In 2015, the Danish wind energy developer Vestas inaugurated a logistical center in Natal to supply equipment to its wind parks. Wobben Windpower, a German turbine company, created a wind tower factory near the city of João Câmara. The Chinese solar company Chint Electrics, the second largest manufacturer of solar panels in the world, set up a manufacturing center in the greater Natal metropolitan region instead of in Ceará state, another potential candidate (Governo do RN, 2017).

By 2015, wind energy in Rio Grande do Norte had already received investments in the order of 7.42 billion USD. The implantation of a regional supply chain has generated employment and income for various classes of professionals, especially during the construction-intensive phase of wind parks. In interviews with researchers, the long-term operational stage was criticized for having a much smaller team of technicians needed to monitor wind park operations (UFRN, Interview, July 27, 2017). The accrual of taxes to municipalities that house wind parks also significantly decreases once construction has ceased. Therefore, while the development of wind energy has brought investments and financial capital to the state, the distribution and long-term sustainability of economic benefits is smaller than industry leaders tend to suggest (da Costa, 2016; Wind Energy Developer, Interview, July 24, 2017).

6.3.2. Supporting regional actors and institutions

Technological partnerships between industry and research institutions promote joint development and implementation of wind and solar-related activities in Rio Grande do Norte. The National Service for Industrial Training (SENAI), which is closely linked to the Brazilian Industry Federation (CNI), was the first organization to offer professional courses to qualify specialized technicians for the wind energy sector. Sharing its facilities in Natal with SENAI, Petrobras's CTGAS-ER research and development center was part of the Brazilian government's original effort to foster the natural gas industry in the country. The CTGAS-ER center has also steadily shifted its internal resources to carry out research in the field of renewable energy and is well-known in Brazil for its research laboratories (CTGAS-ER, Interview, July 24, 2017; Pires et al., 2013). Following the state's participation in the first wind energy auctions, CTGAS-ER and SENAI sought out investors to learn what types of training and qualifications they were looking for in their employees. SENAI also has a cooperative arrangement with GIZ (Germany Corporation for International Cooperation), a German Development Agency, to analyze industry training needs and define occupational standards and training curricula.

The Federal Institute of Science and Technology of Rio Grande do Norte (IFRN) has also undergone a transition to support workforce training and research in the renewables sector.[45] Wind and solar energy-related vocational courses were created when developing these technologies became significant industries in the state (IFRN, Interview, July 27, 2017):

> During the government of Fernando Henrique, the school had some financial problems…With the arrival of President Lula, he gave a new life to the institutes. That's when expansion began to happen and we be began to evolve. These federal institutes continued to grow, the courses grew to meet the demand for local industry and productive arrangements. And there was also this question of creating corresponding programs for

[45] The main campus of the IFRN trade school system was founded in 1909 in Natal, and presently has several campuses throughout the state.

energy. After a while we noticed that there was a demand to have professionals in the area of energy.

Before the first wind energy auction in 2009, the school had been training technicians to meet the demand for labor in the local petrochemical and mining industry, providing courses in fields such as basic mechanics, geology, and electrical. For large-scale wind generators, the initial construction phase is civil engineering-intensive, requiring technical expertise in road construction, metalwork, and molding concrete for wind towers and bases. The Institute first concentrated on adapting its previous experience in related vocational areas to train technicians and specialists in infrastructure construction. Over time, the Institute created other courses that focus on the installation and maintenance of solar and wind technologies, installing solar PV systems on campus rooftops to generate electricity and allow students, professors, and research to conduct research. Professors and academics in the state also claim that the technical institutes are more involved in research and training in renewables than the Federal University of Rio Grande (UFRN), which is known to have a less hands-on and more theoretical focus in its engineering courses (IFRN, Interview, July 27 2017).

6.3.3. Summary

Rio Grande do Norte has been an important regional driver in consolidating the national wind energy sector. Different actors at the state-level have advanced ideas about alternative sources of energy which have been viewed with deep-seated skepticism at the federal level. Many oft-cited policy figures have worked within existing political and resource constraints to nurture ideas and coalitions that have led to the broader, national support of wind policies. Their task has been to persuade others that renewable energy is a vital component in the region's development. Unlike Pernambuco, where the state governor demonstrated a strong, early commitment to renewable technologies, wind advocates in Rio Grande do Norte had to convince state administrations and the state legislature of wind's economic development potential. The state has also had to actively engage with the federal government. After persuading the government to schedule an auction for wind energy, state representatives became active in arguing for the siting of new transmission lines to facilitate the export of wind power to neighboring states. In effect, state officials and wind stakeholder have had to find ways to get around the inertia created by the broader political and technical system that has favored the development of hydroelectricity.

Rio Grande do Norte's involvement in wind and solar has been supported by regional research and training institutions. Place-based sources of knowledge and technological innovation have been important to the development of the national energy system. IFRN and CTGAS-ER have historically had a strong regional focus in their research and training, and have played a significant role in the regional transition to renewables. Within the Lula government's broader shift to more redistributive policies, renewable energy-oriented vocational programs in Natal emerged to attend to the needs of the regional wind industry where graduates are often sent to work on energy projects across the country. Petrobras's has also notably transformed its research and development units to involve renewable energy. Public agencies in charge of environmental licensing have also internalized the state's entrepreneurial approach to renewable energy. Civil servants employed by these agencies maintain working relationships with investors to secure wind and solar projects in the state.

6.4. São Paulo

The state of São Paulo is situated in the Southeast where most of the country's financial and commercial economic activities are concentrated. In addition to being the wealthiest region in the country, accounting for 60% of national GDP, it has one of the highest numbers of installed residential and commercial PV systems (Aneel, 2017). This is due, in part, to high household incomes and the relative cost of electricity in the region. The energy mix for the state of São Paulo contains a considerable amount of renewable sources from small hydroelectric plants and biomass facilities. Sugarcane biomass in particular is responsible for 19% of state electricity production, and corresponds to 53% of installed capacity in biomass in Brazil (Investe SP, 2017).

State energy planning is conducted in a partnership between the São Paulo Secretary of Energy and Mines (SEM) and the state political administration represented by the governor's office. The São Paulo SEM was founded based on the concern that the state needed to redefine its energy model within the national context (Moraes & Simone, 2015). SEM is also in charge of hosting the State Committee for Energy Policy (Cepe), which is responsible for drafting the Energy Plan for the State of São Paulo. The Energy Plan defines the state's long-term planning and public policy goals related to the energy sector. The compatibility of proposed measures is also evaluated in view of the State Policy on Climate Change (PEMC). The current Energy Plan, referred to as "PPE 2030," is under revision, and will establish long-term state commitments to less polluting and carbon emitting energy sources.

6.4.1. The implementation process in São Paulo

The need to strengthen regional energy security in São Paulo has been an important driver in planning the state electricity supply. A reliable electricity supply is a critical issue for energy-intensive industrial activities that are of great importance to the Paulista economy (SP SEM, Interview, Dec. 8, 2016). As the state became more urbanized, and industry expanded from the 1930s onward, São Paulo became a net importer of electricity. The state draws about

63.8% of its electricity from the interconnected grid system. The strong dependence on hydroelectricity from far-way locations has worried energy policymakers in the state because of the increased risk of supply shortages, especially after periods of severe droughts that reduced the water levels of hydroelectric reservoirs and resulted in power rationing in the Southeast. With the depletion of the regional hydroelectric potential in the South and Southeastern states, state energy policymakers have been looking towards diversifying the regional energy supply to guard against future disruptions (SP SEM, Interview, Jan. 5, 2016; SP SEM, Interview, Dec. 8, 2016).

In contrast to Northeastern states, policymakers in São Paulo emphasize that the state lacks the potential to develop wind and solar energy on a large scale. Instead, they are more interested in developing natural gas and the state biomass program.[46] Massive undersea oil and gas deposits off of the state's coast could potentially make it the second largest producer of oil and natural gas in Brazil. In addition, given its industrial background, São Paulo is the largest production of machinery and equipment for petroleum exploration. The extraction of the offshore deposits is beneficial for regional oil and gas companies, refineries, and equipment manufacturers. Representatives from the Secretary of Energy and Mines tend to draw attention to the economic development and environmental benefits of the state's proposal to expand natural gas production. The increased use of natural gas, which, though not a renewable source of energy like wind and solar, is argued by public officials to be relatively clean, and the construction of natural gas-fueled power plants is argued to be less harmful to the environment than hydroelectric plants. Both the state government and the Secretary of Energy and Mines see natural gas as an ideal alternative fuel for high-efficiency thermoelectric plants, with lower pollution rates in comparison to diesel generators.

[46] State energy planners have also expressed interest in using municipal waste for electricity generation and biogas. However, planning difficulties arise because the concession is authorized by municipalities, not the state government, so they have less room to act.

The increased use of sugarcane biomass and biogas in electricity generation would further support the regional sugarcane ethanol industry (Furtado, Scandiffio, & Cortez, 2011). São Paulo has the largest gas pipeline network in the country, transporting natural gas from Bolivia and from the Santos Basin off of the state's coast, which it then redistributes to the neighboring states of Minas Gerais, Rio de Janeiro, and Paraná. There are currently 201 cogeneration plants which operate in São Paulo, 66 of which are 20 km away from the state gas network. A part of the plan is to inject the biogas from these plants into the gas network. The SEM also contends that the use of biomass and biogas also has important synergies for the transport sector. The trucks that transport the sugarcane into the cane fields could run on biomethane, transforming them into flex-fuel vehicles. Simultaneous investments in biomass and biogas are thus characterized as complementing natural gas investments as a "bridge fuel" on the path to more low-carbon and renewable energy sources.

In light of the state's natural gas potential, state policymakers are less committed to developing solar and wind energy. While annual levels of solar irradiation are high in the state, between 5.61 and 5.70 kWh/m²/day (SEM, 2013), many policymakers claim that the current lack of storage technology combined with lower solar irradiation rates in comparison to more Northern states, make solar energy less ideal for utilities-scale generation in São Paulo. The recent deployment of solar photovoltaic and wind power plants near existing hydroelectric plants is considered a way to test the complementarity between the two energy sources. State energy planners underscore the energy efficiency and technical gains from wind and solar while playing down their use for large-scale renewable energy deployment.

Similarly, the use of small-scale distributed solar generation systems is framed primarily as reinforcements for broader goals of regional energy security and efficiency. In Southern

Brazil, where electricity tariffs are high, locating small-scale systems near areas of consumption provides additional security and precludes the need for transmission infrastructure (SP SEM, Interview, Dec. 8, 2016). Like the state of Pernambuco, government officials in São Paulo have been working with public agencies to integrate distributed generation systems in their public building operations. Cogeneration systems, energy storage, and a solar photovoltaic power plant have been installed at the Butantan Institute, the largest producer of vaccines in the southern hemisphere, and the hospital complex of Hospital das Clínicas. The Secretary of Energy and Mines has also worked with the local distribution company, Cesp, to install solar distributed generation systems in the Villa-Lobos and Cândido Portinari municipal parks in the city of São Paulo. Unlike the market-oriented approach of Pernambuco, however, these projects are demand-side measures to improve efficiency in energy-intensive public infrastructure. Small-scale systems are depicted as a supplementary benefit to the overarching mission of regional energy security while providing economic benefits in terms of building up the regional supply chain in solar manufacturing and installation.

6.4.2. **Supporting regional actors and institutions**

Interestingly, state policymakers claim to be less active than their Northeastern peers in terms of attracting firms to the regional renewable energy market. According to one interviewee involved in public project financing, São Paulo is often seen as a natural choice for international firms interested in investing in Brazil. The quality transport and energy infrastructure and proximity to a large capital goods market are sufficient for companies to decide to locate their operation in the region (DesenvolveSP, Interview, June 28, 2017). GE Renewable Energies and Wobben Windpower have two of their major factories in São Paulo and supply wind energy turbines and related equipment to the Southern and Northern wind markets. State officials consider wind and solar manufacturing industries as a boost to economic development (Calixto, 2014), but view their role as maintaining a favorable investment environment vis-à-vis the prerogatives of the Secretary of Energy and Mines.

Lastly, São Paulo hosts the country's leading research institutes and universities which conduct research and development in energy. Representatives from the industrial sector and science and research sectors are frequently invited to advise statewide energy planning efforts. Many of these representatives are policymakers and researchers who focus on sugarcane cultivation and ethanol production, such as the Federation of Agriculture of the State of São Paulo (Faesp) and researchers from the state's public universities. In particular, the São Paulo Research Foundation (FAPESP) is a public taxpayer-funded research foundation and a national leader in R&D for sugarcane cultivation. FAPESP's Bioenergy Research Program aims to promote ethanol technologies, allotting public resources to sustain São Paulo's regional commitment to bioenergy, primarily from sugarcane (FAPESP, 2017).

6.4.3. Summary

In summary, growing concerns about supply reliability have prompted policymakers to develop long-term strategies for energy. In formulating a response to meet state electricity demand, they strategically downplay the natural resource potential of wind and solar. The discovery of the pre-salt oil reserves has placed pressure on state policymakers to promote natural gas and potentially biogas. This is made clear by a Secretary of Energy and Mines representative:

> So, this is the paradigm that we have to confront. On the one hand, we have a gigantic potential of pre-salt coming in. It would be unfair to not use this fuel that has a very low price to leverage our development. So, this is the great challenge that we have at the moment – to find an equilibrium point so as not to compromise our matrix which is comprised of renewables, but also not to compromise our economic development.

Because there are no other cheaper sources than natural gas. This is our great challenge.

The long-term energy planning challenge is framed as a tradeoff between exploiting the pre-salt potential while also stimulating the renewable energy base. São Paulo policymakers are aware that the state's undersea deposits can lead to local profits for the state government in terms of tax revenue, royalties, and job creation, and have attempted to reframe their energy supply strategies in ways that do not ostensibly undermine the state's climate change goals and environmental image. Interviewees also concede that a natural gas expansion can also have substantial negative effects, perhaps enough to offset its expected benefits, given the large amount of carbon dioxide emissions that are estimated to be present in these fields (Almeida, et al., 2017).

Furthermore, due to the high potential of sugarcane biomass and biogas in São Paulo, the state's energy transition was strongly conditioned by energy infrastructure projects and regional energy generation. The state's commitment to biomass and biogas for electricity generation demonstrates the contextualized way in which resources are negotiated as politically compatible with strategic priorities at the regional level. The sugarcane industry induces a certain degree of path dependency, being a mature technology that has been historically favored. This regional lock-in has created inflexibility when faced with a need to adapt to changing energy supply circumstances or considering other socially-beneficial technological options to generate electricity.

6.5. Conclusions

In general, state governments have exercised relative autonomy to set policy agendas and intervene in the broader market formation of solar and wind technologies. In particular, policymakers and policy entrepreneurs draw on regional resource endowments, institutional capacities, and industrial bases in ways that structure the renewable energy options available.

The policy environment at the national level has recognized state-level participation in energy planning and the development of renewable energy projects. For example, the current administration at the Ministry of Mines and Energy is distinguished by a greater effort to interact with state governments, especially for the siting of long-distance transmission lines for wind energy projects (MME, Interview, March 20, 2017). The fact that governors and politicians in the Northeast now directly engage in lobbying for the scheduling of regular auctions for wind and solar projects underlines the growing importance of state governments in constituting energy governance.

Chapter 7

Conclusions

> "Indeed, if technology is understood in its broad sense - as not just hardware or equipment or sprockets or chips, but as any device or system for converting inputs into outputs, for changing the production function - then regulation is itself a technology…Regulation is the technology of governance."
>
> - Wiener (2004, p. 488)

Over the past decades, the trend in energy regulatory reforms has been toward privatization and greater efficiency. This restructuring strategy frames regulators as apolitical entities managing the electricity sector. Within this context, regulatory bodies are understood as strictly economic institutions that are not to become involved in social or environmental concerns. That is, any concern that deviates from the goal of improving competition and managing regulated industries is seen as outside the purview of regulators. Such deviation would undermine the standard model for electricity reform by ostensibly reducing efficiency, burdening regulated industries, and discouraging private investors.

Moreover, while deregulation and market-oriented reforms imply that the lowest-cost technologies should supply electricity, this logic overlooks that fact that new energy technologies must compete with well-established systems. In this way, entrenched energy systems and associated institutional frameworks often prevent the adoption of potentially superior alternatives. Incumbent energy technologies operate by leveraging economies of scale and thereby make entry into the industry difficult for potential new actors. They further co-evolve with institutions and social practices that build, manage, and sustain them. As societal preferences change over time, pre-existing technologies, which were built around a set of assumptions concerning appropriate ways to supply and consume electricity, might not be able to meet emergent social and policy objectives. In this light, renewable energy policies have been developed to stimulate new technological offerings that address growing concerns about energy security and climate change.

While industrialized and industrializing countries have focused their efforts to replace carbon-intensive energy sources, few insights have been generated concerning the relationship between the transition to more renewable energy systems and the underlying regulatory and institutional framework. Instead, public support for renewable energy has centered on subsidizing new technologies and reducing their costs in relation to conventional sources of generation. While regulations are recognized as defining the "rules of the game," the academic literature on technological innovation has characterized regulations as market barriers that reinforce the status quo. Technology and regulation are posed as adversaries (Wiener, 2004). Similarly, but from another view, in popular discourse regulations manifest as "red tape" and administrative hurdles that a persevering private sector must overcome (Mazzucato, 2013). In a free market context, regulations inhibit businesses' innovative edge and competitiveness, rather than encourage technological innovation.

This dissertation contributes a critical perspective to our understanding of the relationship between market-oriented reforms and the adoption of renewable energy. Despite having privatized its energy sector and established independent regulatory agencies, Brazil has not abandoned social and environmental concerns in the electricity sector. Looking inside the world of energy regulators, this dissertation research shows how the regulatory process bears directly on renewable energy deployment. While both policymakers and regulators emphasize Aneel's role as a neutral arbiter, the energy regulatory agency has an instrumental place within policymaking. In making policy through regulating, Aneel develops procedures that respond to its organizational needs for authority and legitimacy. This case shows that energy auctions and net-metering regulations for wind and solar energy illustrate how regulators ensure compliance and assert their authority in ways that enable, rather than hinder, the development of these technologies.

Furthermore, state governments have identified economic and political benefits in deploying non-hydro renewable energy technologies. They have created a number of initiatives to encourage new technologies and facilitate the effectiveness of federal energy auctions to ensure that wind and solar energy develop within their borders. This analysis thus provides a more encompassing explanation of wind and solar development than alternative accounts which merely focus on favorable natural resource conditions and federal incentives.

Since regulatory agencies tend to draw attention to their detached, technical façade when officially discussing politically sensitive decisions (Dubash & Rao, 2008), finding out what regulators *actually do* is not a simple task. I had the rare opportunity to access key actors involved in energy planning in Brazil. By talking with state-level policy-makers, I was able to trace how more "local" processes have influenced federal decision-making and how state responses are conditioned by national policies, or their absence.

7.1. Electricity Market Reforms and Renewable Energy

7.1.1. Understanding Regulatory Governance for Renewable Energy Development

Brazil continues to invest in large hydropower dams, but intense droughts have convinced successive governments over the last fifteen years that there is a need to diversify the country's energy resources. The uncertainty about the performance of the country's hydrological resources has provided an opening for wind and solar technologies. In this sense, Aneel is an innovative and responsive actor with an active role in reshaping the energy supply. Energy regulators have devised lines of regulatory action that target different facets of the well-established hydroelectric system, carving out an opening for wind and solar energy within the broader policy context.

This study's focus on the socio-technical qualities of wind and solar energy shows how existing arrangements in the electricity sector influence the development paths of new, alternative energy technologies. In this regard, technological compatibility with the existing system greatly influenced political decisions about energy supply. Specifically, policymakers framed a technology's suitability based on how it relates to hydroelectric power. Owing to its intermittency, wind energy is widely promoted as a superior complement to the underlying hydropower base. Over time, successive wind auctions have reduced its costs and allowed the government to learn about the technical characteristics of wind power (Arthur, 1988), further reinforcing the notion among policymakers that wind energy is an ideal alternative. In contrast to wind power, energy technologies that do not fit with the existing infrastructure have had less political sponsorship. In the case of solar energy, the Brazilian government has yet to release a clear statement of policy. Brazil has high average levels of solar irradiation, and technology costs have fallen, but the government's public position on solar energy (or lack thereof) has prevented the deployment of photovoltaic technologies. The planning problem for energy diversification is thus one of materiality (Beauregard, 2015), where the pre-existing hydroelectric infrastructure actively frames decision-making about the energy supply, although the political discourse is typically framed in terms of costs.

Reframing wind and solar energy policies as implementation issues shows that regulators base their support for these technologies on criteria or rationale different from those of most policymakers or advocates. As previously noted, current energy regulators' education and experience have made them receptive to alternatives to hydroelectric technologies in comparison to their predecessors. While regulators expressed intellectual and professional interest in renewable technologies during interviews (Aneel, Interview, March, 20, 2017; Aneel, Interview, September 19, 2017), policy preferences were insufficient to explain their motivation and efforts to enforce wind and solar policies. Rather, the regulatory process and shared control over electricity issues shaped regulators' implementation strategies. This explanatory theory accounts for why Aneel prioritizes its resources and regulatory activities to ensure the development of wind and solar energy, even when there is no pre-existing policy and when political support and resources have waned.

The regulatory environment structures the extent to which energy regulators interpret policies and how they engage with regulated interests. In the Brazilian electricity sector, policymakers and the regulatory agency make and implement policy. The MME and Aneel share the day-to-day governance of the electricity sector, where Aneel is officially subordinate to the MME. In practice, Aneel has expanded its authority over several policy areas and interacts closely with market participants. To maintain their authority, regulators must fight over jurisdiction with other agencies and interests. The MME and incumbent administrations have administrative power, but the capacity to effectively govern the electricity sector is contested. Since the quality of rules and regulations becomes a crucial condition for judging effectiveness (Schmelzle, 2011), Aneel's approaches toward enforcement and collaborative rule-making attempt to reinforce its legitimacy and claims to authority. In other words, the regulatory agency's struggle to prove that it is consequential for good outcomes is a core process that governs the electricity system. This has several implications for renewable energy development.

For wind energy, an auction's success is judged based on immediate results, namely if it lowers the price of electricity. However, delayed or abandoned wind projects are prevalent and frequently lead to high transaction costs. These costs are only revealed after an auction has occurred and political leadership has taken credit for the auction's initial low prices and sector growth. In this context, policy enforcement has emerged as a proxy for quality in administering auction schemes. The Ministry of Mines and Energy is responsible for scheduling auctions, but Aneel achieves the goals that auctions were designed to accomplish–the delivery of wind energy projects. That is, the MME plans for new renewable capacity, but Aneel ensures that that capacity is actually developed, which is not a given. By taking a strict approach to enforcing contractual obligations, the regulatory agency reconciles competing political interests with its brand as a policy enforcer and collaborative decision-maker. Aneel's strategy for contract enforcement improves the implementation of wind projects, but also communicates to private developers that they must be able to deliver projects if they wish to participate in auctions. The fact that regulators have indicated their willingness to bar non-compliant developers from future auctions allows the agency to secure its regulatory objectives (Ayres & Braithwaite, 1992). In addition to auction design elements, regulatory behavior attempts to address the risk of unwanted strategic behavior and avoid non-implementation of projects.

At the same time, the agency's interpretation of its mandate and the public interest motivate its implementation strategy. The agency makes judgments about what constitutes legitimate reasons to provide flexibility for project developers, but maintains its posture as an enforcer of contracts. This rigid approach, in comparison to other political actors in the electricity sector, demonstrates its intolerance for project developers that are unable to develop their hard-won auction concessions, thus compromising the public use of scarce resources. Considering the jurisdictional picture, such an approach is also meant to defend the agency's authority in cases where its powers or autonomy have been impeded. The desire to defend its authority and enforce its priorities is translated into strategies that the regulator uses to attain good regulatory outcomes. Ensuring that private sector actors fulfill their contractual obligations is not a straightforward procedure, but depends on how regulators signal their willingness to take action and engage in enforcement (Kovaic, 2015). In sum, when safeguarding jurisdiction and policy objectives are aligned, the effect is a more credible wind sector that signals a low tolerance for less "serious" bidders.

The implementation of auctions also provides opportunities to learn about how to coordinate the expansion of generation and transmission. The regulator's case-by-case handling of wind projects revealed that the closing price for wind energy in future auctions would have to incorporate transmission planning, rather than assume that transmission lines would be ready to connect constructed projects. While the regulated wind industry criticized Aneel's decision to make project developers responsible for future delays causes by transmission, the regulator viewed its decision as responding to information that was previously unavailable. In effect, the regulator was accounting for information and risks that were not reflected in the low auction prices. Energy auctions thus serve as learning processes where successful and unsuccessful examples are incorporated into future auction designs. Policymakers in charge of designing auctions did not anticipate these issues–they were only discovered through the regulatory process.

Furthermore, the case of small-scale solar energy illustrates how regulators create and shape markets for renewable energy. The absence of government policy for solar energy has provided a space for Aneel to take a more proactive approach toward small-scale generation systems. In the case of distributed generation, Aneel has taken the role of conductor in the niche development process, using a gap in policy action to gain authority over an emerging policy area. Rather than developing distributed generation systems through a feed-in tariff, which would have required the involvement of other public authorities, Aneel opted for a net-metering scheme. This allowed the agency to develop distributed generation regulations within its jurisdiction and without formal subsidies. With each revision of the net-metering framework, Aneel identified and changed regulations and standards, gradually making space in the centralized generation system for smaller distributed generation systems. The nature of the regulatory process has allowed Aneel to take an adaptive approach to implementation, adjusting net-metering regulations over time as new information became available.

Aneel's prioritization of distributed generation and wind energy extends into other aspects of its regulatory activities. In addition to creating and modifying rules, Aneel has selectively used its R&D programs to support solar and wind energy, demonstrating its commitment to developing both technologies. Aneel attempts to anticipate how the regulatory framework will need to adapt to technological change. Rather than choosing to stay behind technological change, regulators are responsive to shifting market conditions. In essence, the regulatory process is where new technological choices confront the incumbent electricity system.

The incorporation of small-scale solar technologies, which deviate from a planning model that has favored large-scale hydroelectric power, could critically alter the electricity grid. Distributed generation presents an innovative change to the regulatory structure as it significantly challenges the traditional electric utility business model and how the grid is planned and operated. By taking the lead on distributed generation, Aneel's regulatory procedures and public hearings have realigned actors into coalitions that support distributed generation. In advocating for distributed generation, these alliances present new visions of what they see are economically and politically appropriate ways to generate electricity. In the Brazilian context, small-scale solar energy systems are framed as benign alternatives to large-scale hydroelectric generators and thermoelectric plants. Since they remain in the decentralized control of consumers, distributed generation technologies embody a more ethical vision of producing electricity compared to large-scale hydroelectric projects that the Brazilian government and private construction companies often built in environmentally vulnerable areas.

Regulatory activities will differ from what the designers of policy expect, and knowledge of this fact causes consternation and allegations of regulatory "capture" and private agendas (Wilson 1989; Lin, 2002). Indeed, this tension between rules and discretion underlies the debate on the design of regulatory agencies (Sitkin & Bies, 1994). A perennial concern is that flexibility and discretion may lead to enforcement that reflects regulators' personal objectives, rather than the goals of regulation (Stigler, 1971). Framing regulation as policy implementation, however, draws attention to the activity of those excluded or absent from traditional fora of policymaking (Yanow, 1996). What a policy actually is, therefore, is as much about context as it is about original intent. In the electricity sector, the context is about earning legitimacy in governing market participants.

The implementation of renewable technologies, therefore, requires an understanding of the regulator's organizational context. Under certain conditions, regulatory politics can have positive implications for renewable energy policies. The relative "unease" that exists between public authorities that co-manage the electricity sector has created an environment that motivates Aneel to affirm its position in ways that support wind and solar. This understanding recasts the debate about the purpose of regulations in energy transitions: policy attention needs to focus on cultivating regulatory strategies and not just deploring regulatory barriers. The transition to renewable energy can either be undermined or facilitated by how regulators conceive of their role in supporting renewable technologies. In situations where renewable technologies are at odds with vested interests embedded in the institutional and physical infrastructure, regulatory strategies may be a fundamental source for structural change.

7.1.2. Governing Energy Transitions and Regional Economic Development

The cases of São Paulo, Pernambuco, and Rio Grande do Norte point to a number of factors that explain how states pursue different energy policies, and how renewable energy policy interacts with natural resource endowments. First, referring back to Rabe's (2008) basic framework for understanding a state's motivations to engage in environmental policy-making, these findings suggests that these state governments are primarily driven by opportunities for economic development and regional energy security. State renewable energy policies are often proposed with explicit goals for job creation and industrial development (Rabe, 2004a). Pre-existing infrastructures, such as road networks and ports, are local advantages which contribute significantly to attracting businesses to locate in certain regions. In Pernambuco and Rio Grande do Norte, well-developed port infrastructure and the industrial complexes that have formed around them have been repurposed for wind and solar energy fabrication plants that wish to be more strategically located in relation to the Northeastern energy market. Since state governments want to ensure that these potential benefits are borne out within their jurisdictions, this dynamic can result in inter-regional competition for the renewable energy economy (Stokes, 2013). For example, state governors in the Northeast are now known to travel internationally to attract renewable energy technology manufactures to their regions (Tribuna do Norte, 2017).

Furthermore, regional energy security and self-sufficiency were cited as common planning goals across interviews. Many state governments depend on importing electricity and are consequently vulnerable to the reduced water levels of hydroelectric reservoirs in other locations. The hydro-based electricity system is operated centrally, but the national transmission system creates supply risks and elevated electricity prices that are often shouldered regionally. As a result, states such as São Paulo and Rio Grande do Norte have taken more active measures to mitigate their energy insecurity. Thus, a lack of electricity generation at the regional level cannot be fully explained by a lack of natural resource endowments, but by how states have become embedded in the national transmission system that was planned around hydroelectric expansion.

This is not to suggest that environmental considerations do not factor into statewide energy decision-making. In fact, in Pernambuco there is a strong coalition of public officials who support renewable energy on both environmental and economic grounds. Pernambuco's diesel and natural gas-fired plants were traditionally regarded as a regional economic advantage. Yet, fossil fuels became problematic after a state governor took a more resolute approach to mitigating climate change and greenhouse gas emissions, while being eager to seize the economic development advantages of early involvement in solar energy. Given its institutional focus on cultivating a low-carbon economy, the Secretary for Environmental and Sustainability has also been enthusiastic about renewable energy policies in the state. In contrast, in Rio Grande do Norte, policy entrepreneurs and wind advocates have accentuated the economic development benefits of stimulating wind energy with any environmental improvements from greenhouse gas reduction "framed" as supplemental benefits. While concerns for the environmental and climate change come into play, the promises and opportunities for economic development and improving supply planning have been dominating factors in regional approaches to renewable energy.

Second, decisions to promote non-hydro sources of energy that were seen as marginal at the national levels have often originated from individual actions. In all three cases, policy "entrepreneurs" as well as commitment from state politicians are crucial drivers in regional energy transitions (Hauber and Ruppert-Winkel, 2012; Hecher et al., 2012). A handful of energy civil servants and professionals were repeatedly mentioned when interviewees were describing the origins of certain programs and policy processes. As one interviewee from a diplomatic post explained about renewable energy activities: "Forward-thinking policies in Brazil depend on certain people and resources" (U.S. Gov., Interview, July 19, 2017). In the cases here, a few ambitious policymakers with professional experience in the energy sector drove the initial stages of policy formulation. Given their professional networks and backgrounds, they were often well positioned to see opportunities for new policy and to safeguard political support for their ideas (Rabe, 2004). Policy entrepreneurs in these states have tailored policies to the political and economic realities of their particular settings and have built coalitions. While state government administrations often depend on small staffs to carry out their day-to-day administrative activities, they often act on the information and persuasion of policy entrepreneurs to redirect their administrative capacities to facilitate the regional uptake of renewable energy, especially when broader economic development opportunities are identified.

Third, while some regions have better access to renewable energy resources than others (e.g., wind speed, solar irradiation), resource potential and capacity interact with the contextual conditions in which renewables are developed and deployed. As De Laurentis, Pearson, and

Eames (2016) observe, although these resource assessments are presented by policymakers as essentially "objective," they are strongly influenced by the purposes of the assessment and the actors involved. In São Paulo, for instance, state officials tend to publicize the advantages of natural gas as a clean and locally-produced source of energy that can simultaneously stimulate sugarcane-derived bioenergy. At the same time, they deflect any criticism for espousing an energy path which relies on a non-renewable source of energy. Yet, São Paulo's focus on stimulating the natural gas and sugarcane biomass industries at the expense of deploying wind and solar is not an inevitable outcome. For example, the state of Texas is the largest producer of wind power in the United States, but is also a global hub for oil and gas development (Rabe, 2004a, p. 49; Zarnikau, 2011). Consequently, the way that state policymakers frame energy issues and economic development priorities is an important aspect of guiding choices among different energy futures (Rabe, 2004a, p. 31).

The absence of infrastructure can further influence investments in new energy technologies. The lack of an advanced oil refinery is one reason which prohibited the state of Rio Grande do Norte from generating electricity from fossil fuels. Furthermore, some of the windiest states are serviced by grids that cannot support large inputs from wind farms. Since the National Interconnected System was intended to expand the nation's hydropower potential, energy planners had assumed that Rio Grande do Norte would remain a net importer of electricity. With the successive scheduling of renewable auctions, the high penetration of wind energy in the state has highlighted the importance and challenges of strategic investments in transmission and distribution networks. In response to difficulties in building transmission lines, a number of states with less suitable physical features for wind power have attempted to develop their own wind sources. In a similar manner, the transmission system has also affected the expansion of large-scale solar in Pernambuco, an early promoter of solar energy. There are currently few pre-existing transmission lines that connect to areas of high solar irradiation located in the state's interior. Because of interconnection and transmission issues, the states of Bahia and Rio Grande do Norte have surpassed Pernambuco in terms of planned installed capacity for solar energy.

Fourth, the regional energy context needs to be understood in terms of wider institutional, economic, and governance dimensions. In this regard, these findings have a significant theoretical and conceptual overlap with economic geography and studies of regional innovation systems (De Laurentis, Pearson, & Eames, 2016; Mattes, Huber, & Koehrsen, 2015), which emphasize how energy transitions are shaped by different individual and organizational actors as well as institutions. For instance, prior investments in knowledge formation may be redirected towards emerging technologies (Jacobsson & Lauber, 2006). Science and technology institutions, universities, and distribution companies that engage in R&D and technical training may allocate more resources for renewable technologies as they become increasingly consequential to regional development. In this view, existing regional capabilities can be mobilized through the purposive actions of agents, resulting in the wider development, diffusion, or, in the case of São Paulo, devaluing of a technology (Kemp et al., 1998).

The importance of regional institutions is evident when considering the rapid development of wind and solar energy in the Northeast. While São Paulo has a central role in Brazil's political and economic system, Northeastern states have had an advantage in state and federal universities and institutions that have supported research, development, and job training in wind and solar technology since the 1990s. According to a former university professor turned wind and solar project developer:

> …Brazil is a little atypical. Everything revolves around São Paulo. But, for example, from Rio to São Paulo, nobody understands wind energy. For all that they have, for all of the university institutions, it is difficult to find people that really understand the context of an aerodynamic project, structurally, to really understand it. One of the strong points of Pernambuco is the Federal University. University is knowledge, and from there you're able to develop projects.

Research on the connections between institutions and economic development has pointed to the role of universities in technological innovation and local and regional development. Universities and educational institutions become "task-oriented," taking on specific tasks such as greater technology transfer, more patenting, and visible employment (Srinivas & Viljamaa, 2008). Universities in Pernambuco and Rio Grande do Norte had already built regional expertise in wind and solar before state policy-makers decided to push for wind and solar in large-scale electricity production. These well-established specializations allowed university initiatives to follow once these "new" energy sources gained legitimacy nationally and were consolidated into regional development strategies (Srinivas & Viljamaa, 2008). While national investment and innovation are typically associated with São Paulo, and to a lesser extent Rio de Janeiro, "less favored" regions have developed technology policies and training to attend to regional wind and solar markets.

Lastly, states can serve as strategic spaces for the niche development of renewable energy sources. Verheul and Vergragt (1995) note that niches and associated experiments are promoted by groups which disagree with the conventional interpretations and evaluations of these technologies. In this sense, states have an underappreciated role in demonstrating that wind and solar could compete with incumbent technologies. Pernambuco has been a critical agenda-setter in solar energy policy-making, testing market support ideas that had yet to gain traction at the national level. Interacting within the national policy framework, Rio Grande do Norte has also had a strong impact on wind energy policy by paving a path for other states in terms of environmental licensing and using state resources to help guide interested investors in the competitive bidding process. These policy experiments have provided "decentralized feedback to national policies" (UNCED, 1992), especially for policymakers who administer the rules and oversight for regulated auctions.

7.1.3. Policy Implications: In Support of Adaptive Regulation

Studying regulatory approaches to implementing wind and solar energy policies tells us that we should be circumspect about leading theories of regulatory politics and reform. These theories express valid concerns in conceding authority on public policy issues to regulatory agencies. Such agencies could be used as mere "arms of the state" or pursue an unrestrained range of aims at the cost of sectoral performance. However, policy analysts should not unquestioningly concede that agencies involved in policymaking are necessarily "captured" or afflicted with weak legitimacy, which could mean a reaffirmation of regulatory reform models which may do better at describing the last decades than predicting the next (Wiener, 2004, p. 496). On the contrary, regulations can be crafted in ways that guide emerging technological alternatives. We may thus need new theories to explain the evolution of regulatory institutions in policymaking.

Returning to the stark line often drawn between policy and regulation, there is a long-standing tension between acquiring new renewable resources and regulating markets. In this sense, policymakers develop and refine feed-in tariffs and auction schemes to "acquire" renewable energy as a way to increase its share within the electricity supply. In managing markets, regulators monitor renewable energy policies and engage with market participants in both punitive and collaborative ways. They also change conditions in the market so that new renewable technologies are developed without the need for subsidies or other interventions. As I discussed in this dissertation, regulating and managing markets and renewable resource acquisition are, in fact, complementary strategies. Renewable energy programs create conditions that demand new approaches to regulation, and regulation creates conditions that lead to participation and the implementation of renewable energy programs.

In Brazil, supply auctions for wind energy are biased in favor of strategies that are easy to quantify. Policy analysts focus on increasing project developers' financial and technical qualifications to participate in auctions. This would not be a serious issue if verifying that a project developer is "good on paper" were all (or most of) what needs to be done. In practice, regulators play a critical role in defining the quality of market participation. This depends, however, on the commitment of regulators to enforce contracts and transparently collaborate with stakeholders. Characteristics like these may be difficult to quantify, but they are certainly observable and important to take into account when assessing renewable energy outcomes.

Moreover, policymakers should critically view definitions of regulatory stability that prioritize the interests of private investors over other policy claims. A common argument is that regulatory stability is a key factor in attracting new investments to any sector (Bellantuono, 2017). In the energy sector, both private investors and advocates of renewable energy argue the transition to a low-carbon economy requires an almost exclusive focus on measures that could increase regulatory stability. In challenging and elaborating on this concept, I argue that both the goal of regulatory stability and the means to obtain it are in need of clarification. While investors are naturally interested in reducing the risks stemming from regulatory changes, regulatory risks can be managed even when the public interest requires changing the regulatory framework (Bellantuono, 2017, p. 274). The challenge of increasing investments in renewable energy does not rest exclusively on a lack of stability.

To improve outcomes for renewable energy, regulators at Aneel provide reasonable levels of predictability for market participants while adapting regulations to keep pace with social and technological change. Striking a balance between these two objectives is difficult but critical for the long-term governance of wind and solar energy. Consequently, adaptive regulation does not necessarily have an adverse impact on investors or imply an infringement on their legitimate expectations. This dissertation argues that a much more realistic goal is to increase the credibility of the regulatory framework for renewable energy investors (Bellantuono, 2017, p. 292). What matters is not only the formulation of renewable energy policy, but how regulators respond to changing market conditions according to procedures that are transparent. Recognition that the stability of a regulatory system is not always desirable or necessarily implies lower investment risks can open up new possibilities for improved renewable energy policies.

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Appendix A
List of Interviews

Table A1. List of Interviews

No.	Date	Location	Title	Affiliation
1	7/20/17	Natal	Engineer	CERNE
2	1/5/16	São Paulo	Secretary of Energy	State energy agency (SP SEM)
3	6/5/17	São Paulo	Partner	Totum Institute
4	9/19/17	Brasilia	Superintendent of Generation	Aneel
5	11/10/16	São Paulo	Project Developer, Trade Association Board Member	Solar Energy Company
6	3/21/17	Brasilia	Secretary of Planning	Ministry of Mines and Energy
7	7/13/17	Recife	Program Manager	Secretary of Sustainable Development and Environment
8	7/26/17	Natal	Professor	Federal University of Rio Grande do Norte
9	9/14/17	Brasilia	Director	Aneel
10	7/21/17	Natal	Environmental Coordinator	Institute of Sustainable Development and Environment
11	7/13/17	Recife	Director	State Economic Development Agency
12	1/5/16	São Paulo	Program Manager	State energy agency (SP SEM)
13	6/22/17	Natal	Director of Technology and Research	CERNE
14	9/25/17	São Paulo	Scientist/Technical Manager	SP State Environmental Agency
15	7/14/16	Campinas	Professor	State University of Campinas (Unicamp)
16	3/20/17	Brasilia	Regulatory Specialist	Aneel
17	7/12/17	Recife	Secretary of Energy	Pernambuco Secretary of Energy (Sdec)
18	6/28/17	São Paulo	Managing Director	DesenvolveSP
19	7/17/17	Recife	Principal/Founder	Eolica Technology
20	7/27/17	Natal	Professor	Federal Institute of Rio Grande do Norte
21	7/27/17	Natal	Professor	Federal University of Rio Grande do Norte
22	3/24/17	Brasilia	Public Affairs Representative	BNDES
23	10/7/15	Campinas	Professor Emeritus	State University of Campinas (Unicamp)

24	9/19/17	Brasilia	Regulatory Specialist	Aneel
25	3/21/17	Brasilia	Representative	APINE
26	12/6/16	São Paulo	Sub-secretary of Renewable Energy	State energy agency (SP SEM)
27	7/27/17	Natal	Director	Federal Institute of Rio Grande do Norte
28	1/7/16	São Paulo	Superintendent	State energy regulatory agency (ARSESP)
29	9/23/16	Porto Alegre	Economist	Bank of Regional Development (BRDE)
30	9/19/17	Brasilia	Regulatory Specialist	Aneel
31	7/21/17	Natal	Environmental Licensing Coordinator	Institute of Sustainable Development and Environment
32	7/27/17	Natal	Executive Director of Projects	CTGAS-ER
33	2/3/16	São Paulo	Executive	Wind industry trade association (Abeeolica)
34	7/24/17	Natal	Environmental Services Manager	Wind Energy Development Company
35	7/19/17	Recife	Foreign Services Officer	U.S. State Department
36	7/5/16	São Paulo	Program Manager	Greenpeace Brazil
37	7/13/17	Recife	Director and Engineer	Hydroelectric Company of San Franciso (Chesf)
38	4/3/17	Rio de Janeiro	Representative	EPE
39	6/22/17	Natal	Data Coordinator	CERNE
40	3/20/17	Brasilia	Superintendent of Regulations	Aneel
41	4/24/17	Rio de Janeiro	Manager of Project Financing	BNDES Energy Division
42	3/20/17	Brasilia	Representative	ABRADEE
43	9/23/16	Porto Alegre	Director of Energy	Rio Grande do Sul Secretary of Mines and Energy

Appendix B
Aneel's Estimates of Distributed Generation Growth (2017)

Table B1

Projected number of net-metering customers in Brazil (2017-2024) (Aneel, 2017)

Year	Residential	Commercial	Total
2017	23,794	3,040	26,834
2018	51,683	5,917	57,600
2019	94,310	10,196	104,506
2020	157,776	16,434	174,210
2021	250,758	25,362	276,120
2022	383,010	37,903	420,913
2023	565,448	55,156	620,604
2024	808,357	78,343	886,700

Table B2

Projected amount of installed capacity (MW) from distributed generation in Brazil (2017-2024)

Year	Residential	Commercial	Total
2017	71	30	102
2018	155	59	214
2019	283	102	385
2020	473	164	638
2021	752	254	1,006
2022	1,149	379	1,528
2023	1,696	552	2,248
2024	2,425	783	3,208

Appendix C
Sample Recruitment E-mail

Original Format in Portuguese:

Prezado(a) Senhor(a) ________,

Bom dia. Tudo bem?

Sou pesquisadora e estudante de doutorado na Columbia University in New York City. O objetivo geral das minhas pesquisas é entender melhor as políticas públicas e regulatórias que vão desenvolvendo as fontes alternativas no Brasil, em particular a energia solar e eólica.

Dado o seu histórico em trabalhar com essas questões no ______, estou entrando em contato para ver se existe a possibilidade de fazer uma entrevista com o(a) senhor(a). Se a resposta for positiva, poderiamos marcar um encontro no dia e hora que for conveniente para ambos. A entrevista demoraria entre 30 minutos e 1 hora, dependendo da sua disponibilidade.

Imagino que o/a senhor(a) tenha outras prioridades, mas, acho que a sua colaboração seria fundamental para o entendimento do mercado de energias alternativas no Brasil. É essencial analisar a perspectiva do _____, já que a agência tem um papel importante na gestão do setor e também na disseminação dessas fontes.

Apenas para constatar, a sua participação seria anônima e voluntária. Estou à disposição para quaisquer esclarecimentos. Se tiver alguma dúvida sobre esse estudo, pode ficar em contato também com meu orientador na Columbia, Dr. Robert Beauregard, no rab48@columbia.edu.

Muito obrigada. Fico no aguardo.

Atenciosamente,
Amanda Bradshaw

English Translation:

Dear Sir/Madam ________,

Good morning. How are you doing?

I am a researcher and doctoral student at Columbia University in New York City. The general objective of my research is to better understand the public policies and regulations that develop renewable sources of energy in Brazil, in particular solar wind.

Giving your background in working with these issues at ______, I was wondering if it would be possible to conduct an interview with you. If you agree, we could schedule a date and time that works for you. I estimate that the interview would last in between 45 minutes and 1 hour, depending on your availability.

I imagine that you must have other obligations, but I think you're participation would be fundamental for understanding the renewable energies market in Brazil. It's essential to understand your organization's perspective, since it has an important role in the energy sector and also in the dissemination of these sources of energy.

Just to let you know, your participation in this study is anonymous and voluntary. I am available for any clarifications. If you have any questions about this study, you can also contact my adviser at Columbia, Dr. Robert Beauregard, at rab48@columbia.edu.

Thank you. I look forward to hearing from you.

Best regards,
Amanda Bradshaw

Sample Interview Outline No. 1

Note: This interview guide was tailored for an early interview with someone who had general experience in both federal and local-level energy policies.

INTRODUCTION SCRIPT

Em primeiro lugar, agradeço sua participação nessa entrevista.

Sou estudante de doutorado na Columbia University em Nova Iorque. Também sou orientada por um professor da Unicamp que trabalha na área de planejamento energético.

O objetivo geral dessas pesquisas, que fazem parta da minha tese de doutorado, é entender melhor como as fontes renováveis não hidráulicas estão sendo desenvolvida aqui no Brasil. Estou fazendo entrevistas com pessoas que trabalham nesse âmbito porque queria saber como isto acontece na prática, além de saber suas opiniões como as políticas estão funcionado. As informações que você fornece estarão protegidas e só disponíveis para mim e meu orientador nos Estados Unidos, o Professor Robert Beauregard. Só ele e eu temos acesso a esses dados. Se tem uma pergunta que não queria responder, não precisa, ok? Também queria gravar essa entrevista, já que me ajuda em revisar a nossa conversa depois.

PRELIMINARY QUESTIONS

1. Qual é o papel do seu departamento dentro do ______? Por favor, descreva as atividades da sua organização com relação ao setor de energia renovavel.

FEDERAL ENERGY POLICY

2. Um dos objetivos principais do meu estudo é entender melhor a participação do governo federal em estimular o crescimento de fontes renováveis. Enfim, na sua visão, o que esta funcionando e o que não esta funcionando?

3. Na sua opinião, qual eh o papel da Aneel para fomentar a participação de fontes renováveis?

4. Na sua avaliação, como eh que as leiloes de transmissão que o governo esta planejando vão afetar o setor eólica?

5. Você tem observado se o atual ambiente econômico já esta impactando as fontes renováveis?

6. Na sua avaliação, qual é a experiência do setor de energia eólica com o modelo atual de leilões para a contração de energia?

REGIONAL POLICY

7. Eu também gostaria de entender a importância dos governos regionais no planejamento de energia eólica e solar no Brasil. Na sua opinião, as politicas energéticas desses estados são importantes?

8. Tem outras medidas que os estados ou governos regionais podem tomar?

CLOSING

Tem mais outra observação que você gostaria de colocar?

Muito obrigada pela oportunidade de conversar hoje contigo.

English Translation:

INTRODUCTION SCRIPT

Before beginning, I'd like to thank you for agreeing to participate in this interview.

I'm a doctoral student at Columbia University in New York. I am also associated with a professor at Unicamp who works in the area of energy planning.

The general objective of my study, which is based on my PhD thesis, is to better understand how non-hydro renewable energy sources are being developed in Brazil. I am conducting interviews with people who work in this field because I would to know how this happens in practice, and also know your opinions about how these policies are working out. The information you provide is protected and only available to me and my adviser in the United States, Professor Robert Beauregard. Only he and I have access to this data. If there is a question you did not want to answer, you don't have to respond, okay? If it's ok with you, I also would like to record this interview as it helps me review our conversation later on.

PRELIMINARY QUESTIONS

1. What is the role of your department within ______? Please describe your organization's activities in relation to the renewable energy sector.

FEDERAL ENERGY POLICY

2. One of the main objectives of this study is to better understand the role of the federal government in stimulating the growth of renewable sources. In your view, what are some policies that are working, and not working?

3. In your opinion, what is the role of Aneel in promoting renewable sources?

4. In your assessment, how will the transmission auctions that the government is planning affect the wind sector?

5. Have you noticed if the current economic environment is already impacting the growth of renewables?

6. In your assessment, what is the experience of the wind power industry with the current model for energy auctions?

REGIONAL POLICY

7. As part of this study, I would also like to understand the importance of regional governments in wind and solar planning in Brazil. In your opinion, are the energy policies of these states important?

8. Are there any other measures that states or regional governments can take to develop these sources?

CLOSING

Is there anything else you would like to say before we finish the interview?

Thank you so much for the opportunity to talk with you today.

Sample Interview Outline No. 2

Note: This interview guide was tailored for an interview conducted during the middle of the study, with someone who had extensive experience with regulations for distributed generation.

INTRODUCTION SCRIPT

Em primeiro lugar, agradeço sua participação nessa entrevista.

Sou estudante de doutorado na Columbia University em Nova Iorque. Também sou orientada por um professor da Unicamp que trabalha na área de planejamento energético.

O objetivo geral dessas pesquisas, que fazem parta da minha tese de doutorado, é entender melhor como as fontes renováveis não hidráulicas estão sendo desenvolvida aqui no Brasil. Estou fazendo entrevistas com pessoas que trabalham nesse âmbito porque queria saber como isto acontece na prática, além de saber suas opiniões como as políticas estão funcionado. As informações que você fornece estarão protegidas e só disponíveis para mim e meu orientador nos Estados Unidos, o Professor Robert Beauregard. Só ele e eu temos acesso a esses dados. Se tem uma pergunta que não queria responder, não precisa, ok? Também queria gravar essa entrevista, já que me ajuda em revisar a nossa conversa depois.

PRELIMINARY QUESTIONS

1. Qual é o papel do seu departamento dentro do ______? Por favor, descreva as atividades da sua organização com relação ao setor de energia renovavel.

REGULATIONS FOR 482 (DISTRIBUTED GENERATION)

2. Então, para começar, o(a) senhor(a) pode falar um pouco sobre seu papel na criação e revisão da 482?

3. O(A) senhor(a) prevê algumas novidades com essa próxima revisão da 687 que está chegando?

4. Será que a Aneel vai seguir uma estratégia ou postura diferente essa vez? Por exemplo, eu ouvi falar que nessa próxima revisão, não vai ter tanto subsidio para geração distribuída. O(A) senhor(a) pode comentar um pouco sobre isso?

5. As distribuidoras estão se comportando de uma maneira diferente?

6. O(A) senhor(a) tem percebido alguns “conflitos” entre os grupos que apóiam fontes diferentes para geração distribuída? Porque parece que tem pessoas que apóiam biomassa, eólica, etc. além do energia solar.

7. Já que a geração distribuída está crescendo no Brasil, o(a) senhor(a) acha que outros atores do governo se envolverão mais em sua gestão?

STATES AND DISTRIBUTED GENERATION

8. O(A) senhor(a) observou se os governos estaduais estão desenvolvendo iniciativas para apoiar a geração distribuída? Por exemplo, além de isentar o ICMS, alguns estados estão discutindo a criação de programas de financiamento para esses sistemas.

CLOSING

Tem mais outra observação que você gostaria de colocar?

Muito obrigada pela oportunidade de conversar hoje contigo.

English Translation:

INTRODUCTION SCRIPT

Before beginning, I’d like to thank you for agreeing to participate in this interview.

I'm a doctoral student at Columbia University in New York. I am also associated with a professor at Unicamp who works in the area of energy planning.

The general objective of my study, which is based on my PhD thesis, is to better understand how non-hydro renewable energy sources are being developed in Brazil. I am conducting interviews with people who work in this field because I would to know how this happens in practice, and also know your opinions about how these policies are working out. The information you provide is protected and only available to me and my adviser in the United States, Professor Robert Beauregard. Only he and I have access to this data. If there is a question you did not want to answer, you don’t have to respond, okay? If it’s ok with you, I also would like to record this interview as it helps me review our conversation later on.

PRELIMINARY QUESTIONS

1. What is the role of your department within ______? Please describe your organization's activities in relation to the renewable energy sector.

REGULATIONS FOR 482 (DISTRIBUTED GENERATION)

2. So, to begin, can you tell me a bit about your role in creating and revising amendment 482?

3. Do you foresee some new changes with this upcoming revision of amendment 687 that is coming?

4. Do you think Aneel is going to follow a different strategy or posture at this time? For example, I heard that in this next review, there will not be a subsidy for distributed generation. Can you comment a little on this?

5. Are distribution companies behaving differently?

6. Have you noticed "conflicts" between groups that support different sources for distributed generation? Because it seems that there are people who support biomass, wind, etc. besides solar energy.

7. Since distributed generation is growing in Brazil, do you think other government actors will be more involved in its management?

STATES AND DISTRIBUTED GENERATION

8. Have you looked at whether state governments are developing initiatives to support distributed generation? For example, in addition to exempting state value-added taxes, some states are discussing the creation of funding programs for such systems.

CLOSING

Is there anything else you would like to say before we finish the interview?

Thank you so much for the opportunity to talk with you today.

COLUMBIA | RESEARCH
Human Research Protection Office
Institutional Review Boards

March 9, 2017

Robert Beauregard
5010703 - ARH Urban Planning, PhD

Protocol Number: IRB-AAAN7415
Title: Renewable Energy and Electricity Reforms in Brazil
Approval Date: 03/08/2017 Expiration Date: 03/07/2022
Event Identifier: Renewal (Y02M00)

The above-referenced event was reviewed by Columbia University MS IRB.

Level of review and outcome: Determined to be Exempt

To view a list of documents that were included in this approval (if applicable) and all other currently approved documents for this study, please refer to the Print Menu for this Event in Rascal. It is important to confirm the status of each document, e.g., active, stamped, etc. Only stamped, active documents can be used with research participants.

Study Status: Open to enrollment or ongoing review of records/specimens

Modifications:
-Robert Beauregard named as PI.
-The focus has changed since initial research was completed. Additional interviews with policymakers will be conducted. Residents will no longer be interviewed.
-Target enrollment reduced to 40.

Important Reminder:
-Amanda Bradshaw's human subjects training certification will expire on 5/17/17. She must complete the TC0087 refresher course on or before that date.
-Please submit all renewals well before the expiration date to avoid lapses in approval.

Electronically signed by: Barry, Annie

154 Haven Avenue, 1st Floor New York, NY 10032 212-305-5883 Tel 212-305-1316 Fax
615 West 131st Street, 3rd Floor New York, NY 10027 212-851-7040 Tel 212-851-7044 Fax

Columbia University IRB
Approved for
use until: 03/07/2022